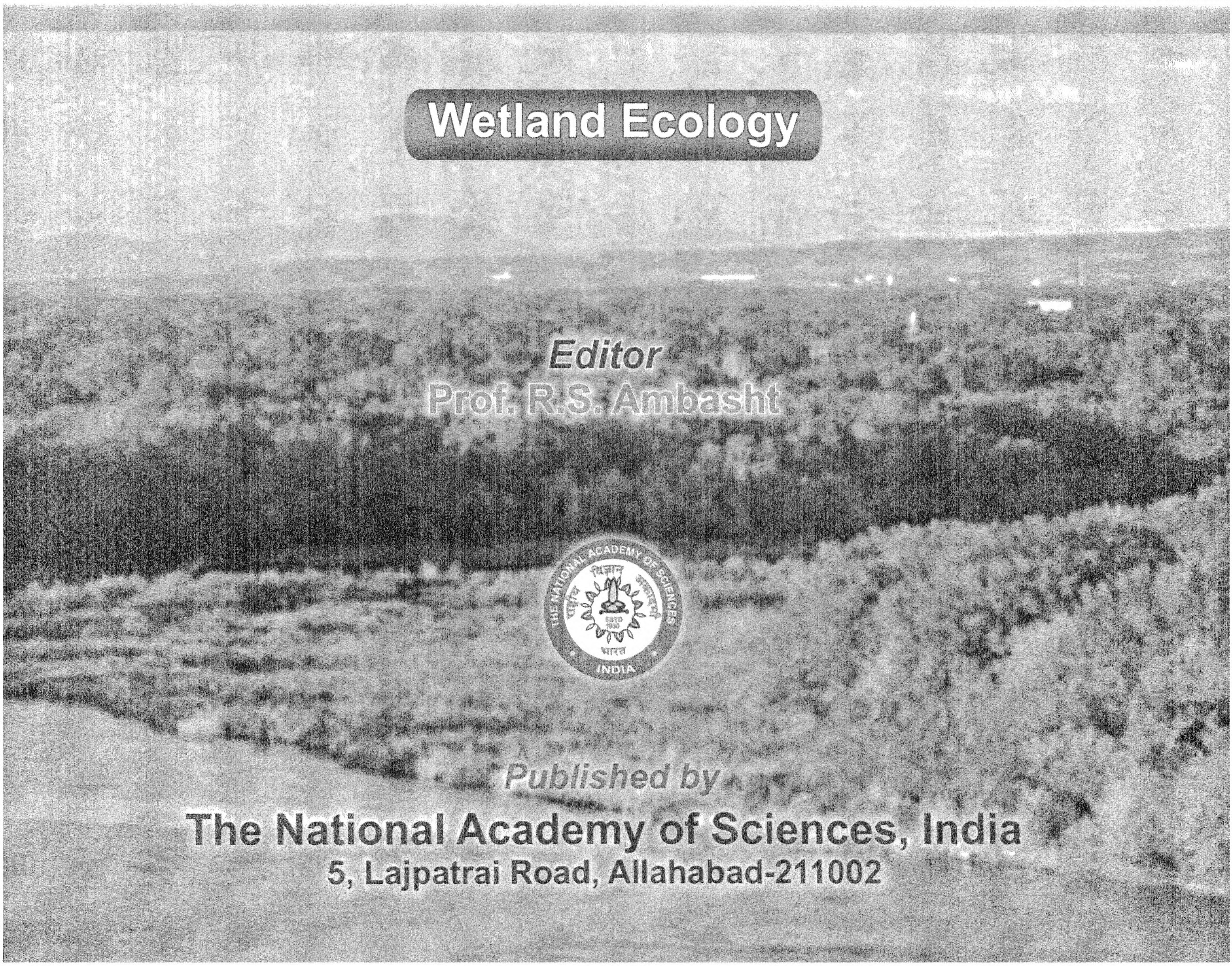
Vol. 78, B, Special Issue, 2008

ISSN 0369-8211

Proceedings of the National Academy of Sciences, India

Section B - Biological Sciences

Special Issue



Wetland Ecology

Editor

Prof. R.S. Ambasht

Published by

The National Academy of Sciences, India

5, Lajpatrai Road, Allahabad-211002

PROCEEDINGS
OF THE
NATIONAL ACADEMY OF SCIENCES, INDIA

SPECIAL ISSUE
ON
WETLAND ECOLOGY

Editor

R.S. AMBASHT

5, Lajpatrai Road, Allahabad, 211002

POSTAL ADDRESS
The National Academy of Sciences, India
5, Lajpatrai Road, Allahabad - 211 002, India

TELEGRAPHIC ADDRESS
NATACADEMY
Phone : +91-0532-2640224
FAX
091-0532-2641183

E-MAIL
nasi@sancharnet.in

WEBSITE
www.nasi.org.in

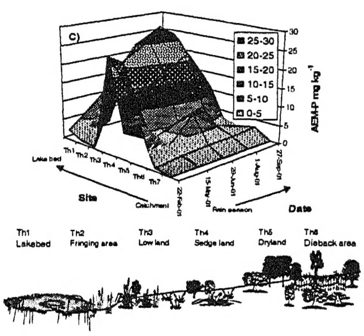
Published by Prof. P.K. Seth, General Secretary for The National Academy of Sciences, India, 5, Lajpatrai Road, Allahabad-211 002 and Printed by Apex Graphics, Allahabad.
Managing Editor : Prof. G.K. Srivastava
Co-Sponsored by C.S.T., U.P., Lucknow.

CONTENTS

Proc. Nat. Acad. Sci. India, Sect. B, Vol. 78 Pt. Special Issue, 2008

Range of wetland types and definitions are reviewed and important wetlands of the world in general and of India in particular are described. Brief reviews on productivity characteristics, conservation values of vegetation, eutrophication, biochemical oxygen demand, biological magnification and eutrophication are given.

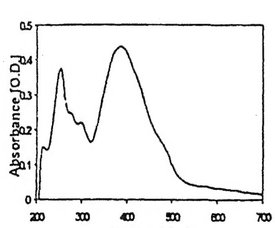
The role of the scientific community in determining an appropriate research agenda is key to effective governance and management of wetland ecosystems world-wide.



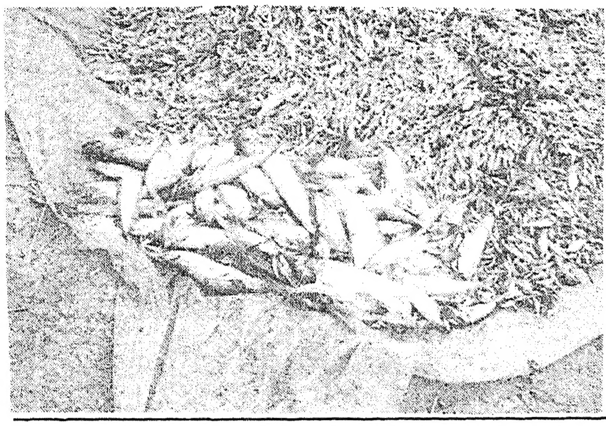
This review focuses on a number of small wetlands near Perth, Western Australia, covering the issues of litter production, rates of decomposition and P leaching, subsequent interactions of leachate with soil and microbial biomass, and the mobility of nutrients.

S.No.	Wetland site	Number of species**	Annual increment of macrophytes (gm^{-1})	Community architecture***
1	Nowgam	21	845	Dominated by tall growing emergents
2	Malangpora	42	1790	Dominated by sedge- meadow species
3	Tullamulla	35	1840	Dominated by sedge - meadow species
4	Mirgund	20	730	Mainly dominated by tall growing emergents
5	Shalabogh	19	3073	Mainly dominated by tall growing emergents
6	Kranchu	32	846	Mainly dominated by tall growing emergents
7	Malgam	37	312	Mainly dominated by tall growing emergents
8	Haigam	29	1886	Dominated by low growing emergents and tall growing emergents take the position of a dominants

The overall deterioration of wetlands, due to diverse and intense anthropogenic pressures leading not only to the eutrophication but also the shrinking of these economically and ecologically important ecosystems, has resulted in the loss of much of the biodiversity.



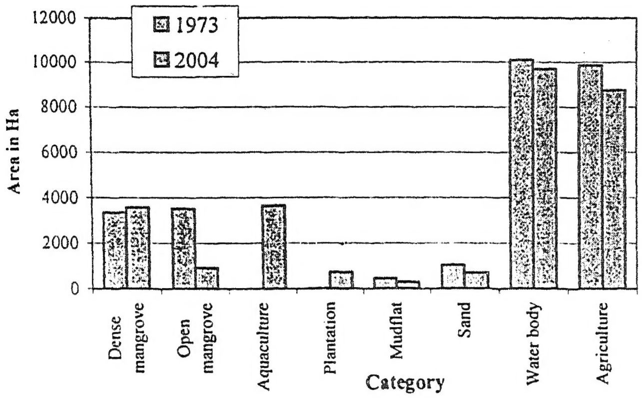
UV-B can cause wide ranging effects leading to mutation and death of cyanobacteria. However, they have developed protective mechanisms to mitigate the damaging effects of UV-B.



Threatened wetlands need rehabilitation to enhance fish production in India

V.R.P. Sinha and B.C. Jha 67

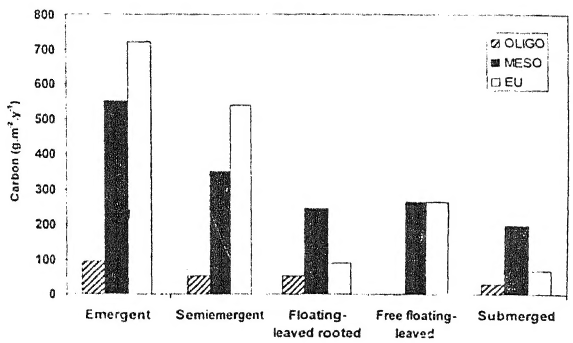
India has sizeable area of freshwater wetlands (>0.15 million ha) and coastal wetlands. Besides being a repository of aquatic biodiversity these ecosystems perform as host for utility functions like fisheries, food, fodder, fuel, medicine, tourism, water supply and irrigation. But unfortunately its degradation and deplition is posing threat to many ecosystems. There is a need for appropriate restc ration measures.



Mapping, monitoring and conservation of Mahanadi wetland ecosystem, Orissa, India using remote sensing and GIS

Chiranjibi Pattnaik, C. Sudhakar Reddy, S. Narendra Prasad 81

The present study deals with periodic assessment and monitoring of the mangroves of Mahanadi delta, Orissa using remote sensing and GIS techniques. A loss of 2606 ha mangrove area and an increase of 3657 ha aquaculture area have been observed during 30 years.



Carbon accumulation by macrophytes of acqutic and wetland habitats with standing water

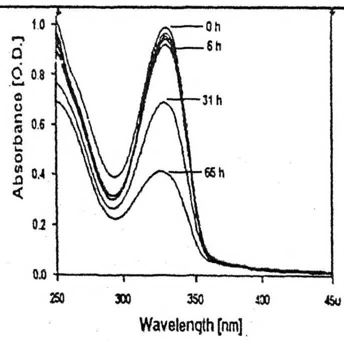
Jan Květ, Jan Pokorný and Hana Čížková 91

Data on the biomass and net primary production by acquatic macrophytes, have recently been evaluated from the view point of the carbon content of the macrophytes. The storage of organic carbon in any macrophyte community is the result of a balance between its net production and decomposition of the plant remnants.

Land-water ecotone ecology

R.S. Ambasht and Navin K. Ambasht 99

Wetland margins overlapping adjacent uplands are called ecotones. They are richer in biodiversity and often exhibit cyclic hydric and xeric succession. Conservation efficiencies of ecotone vegetation for soil, water and nutrients are quantified.

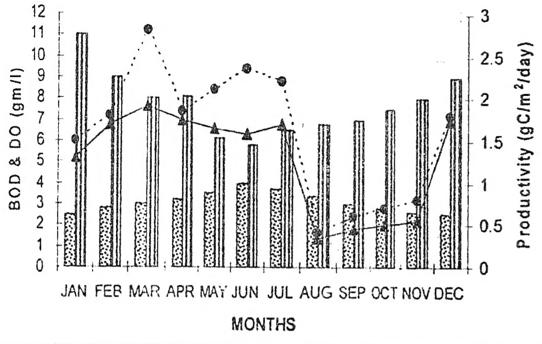


Effects of UV-B radiation on phytoplankton and macroalgae: Adaptation strategies

R.P. Sinha, S.P. Singh and D.P. Häder 105

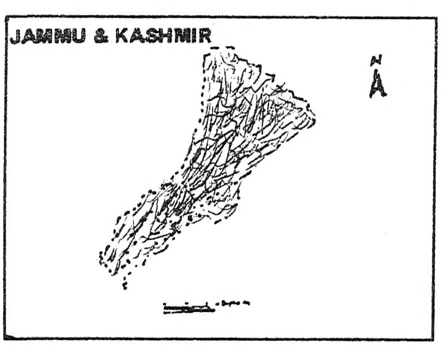
Phytoplankton and macroalgae are the major biomass producers. They form the basis of the aquatic food webs. UV-

B can cause reduction in development and reproduction resulting into loss in productivity of phytoplankton and macroalgae. However these organisms have developed certain adaptation strategies to counteract the damaging effects of UV-B.

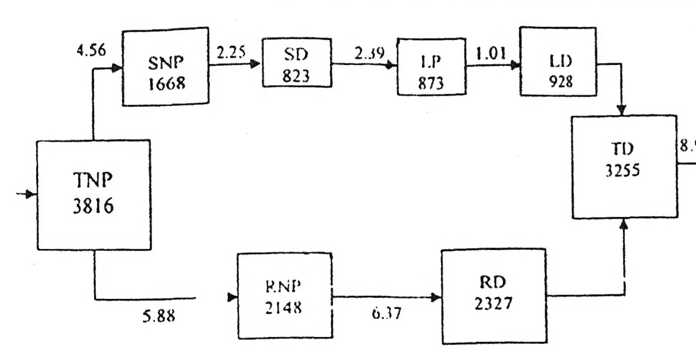


Inverse relationship between Biochemical Oxygen Demand (BOD) and Dissolved Oxygen (DO), and positive relationship between DO and Phytoplankton productivity were established during the physico-chemical and biological examination of Surhatal wetland.

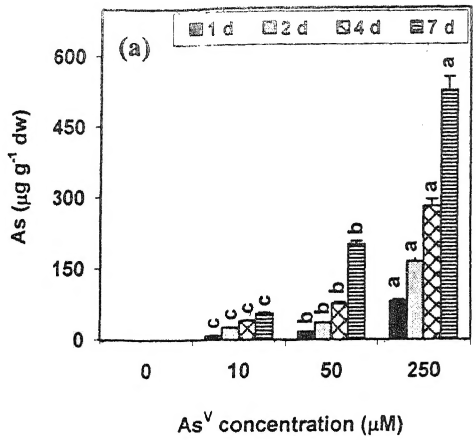
Loktak lake in North East India with its unique biodiversity is under Montreax Record indicating priority is to be given for conservation. Using IRS-1C, IRS-1D, PAN data and IKONOS, a detailed study of this lake and its catchment area is done using Remote Sensing and Geospatial technology which generates various thematic maps.



Remote sensing and GIS have been involved in water quality assessment since decades. In the present study, PLOAD (Pollution Load) model with a geographic information system (GIS) interface was used to estimate pollutant levels. The datasets used in the study included Landsat image, 90 m digital elevation model, ancillary data, pollutant loading rate data (lb/ac/yr) and field data.



The present study is undertaken to evaluate the primary productivity and dry matter dynamics of grasslands of KLNP. The seasonal and annual drymatter production, its transfer through different producer compartments, net accumulation rates, disappearence rates and turnover were calculated.



Role of aquatic macrophytes in arsenic photoremediation in wetlands

Rudra D. Tripathi, Seema Mishra and Sudhakar Srivastava 167

Arsenic toxicity has emerged as a serious problem during last few decades. As an environment-friendly and cost-effective technology, phytoremediation may be used effectively to remediate the contaminated areas. This review focuses on the problem of arsenic contamination, the relevance of phytoremediation as a solution, importance and strategies of aquatic plants for the purpose and probable biotechnological solutions.

The contents of this publication are indexed in:

Science Citation Index Expanded (also known as SciSearch), Journal Citation Reports/Science Edition, Biological Abstracts, BIOSIS Previews and Zoological Records of Thomson Reuters, Philadelphia, USA. For free access to the journal, please see the website-http://nasi.iiita.ac.in/library

FOREWORD

The Biological Sciences (B) Section of the Proceedings of the National Academy of Sciences, India has been publishing, for the last several years, an annual special issue devoted to a subject of current national interest. Conservation of the wetlands has received much attention in recent years as a significant environmental challenge because of its effects on multiple areas of human sustenance. The global concern is evident by the acceptance of the Ramsar Convention for Conservation of Wetlands by almost all the countries. The subject is of special importance for India, and other developing countries, because of the effect of wetland changes on natural ecosystems including the flora and fauna that sustain the livelihood of rural population in many parts of these countries.

Prof. R.S. Ambasht, a member of our Editorial Board, kindly accepted the responsibility of editing this issue. He has successfully got together a distinguished group of contributors from India and abroad to review the total spectrum of problematic issues and possible approaches to their remediation. Dr. Bridgewater's intimate long association with the Ramsar Convention has enabled him to provide the current global scenario and envisaged conservation measures. Similarly, Jan Kuět et al. discuss the problem of carbon accumulation in a global context. There are several chapters reviewing status of various sustaining and adversely affecting factors in the India. Further, in addition to some Indian case histories, an Australian case history has been provided by Ziun et al.

We hope the publication will be useful reference volume to research workers and academicians interested in various facets of wetland conservation. It should be able to provide, in a properly documented form, necessary data to policy planners and administrators. The Science Communication Program of the Academy tries to provide a balanced view on scientific and technological issues concerned with national welfare. I sincerely hope that the present volume will contribute to this effort of the Academy

I am grateful to Prof Ambasht for his valuable inputs to ensure comprehensive coverage and timely publication of this volume. I would like to thank our distinguished contributors for accepting our invitation and their commitment in kindly adhering to our format and rather strict deadlines. We shall welcome comments and suggestions by the readers.

B.N. Dhawan
Chief Editor

PREFACE

Wetlands are currently drawing attention of scientific community particularly those who are involved in ecology, environment, hydrology, food production, human health and certain industries. Rapid losses of wetlands and degradation of their water quality are serious problems. Nearly all the countries of the world are the signatories of Ramsar Convention which is devoted to conservation of global wetlands. The National Academy of Sciences, India, as a follow-up of its Platinum jubilee activities rightly decided to focus attention on wetland ecology through a special volume of its proceedings and myself a member of the Editorial Board was invited to take up the responsibility.

At the outset, I have given an overview of the subject, types of wetlands, ecological characteristics, problematic issues and wetland values. 'Healthy wetlands and healthy people' is the theme of Ramsar convention for the year 2008 and its erstwhile Secretary General Peter Bridgewater has not only discussed it at length but has also developed guidelines for achieving it. He has especially highlighted the role of scientific community in determining appropriate research agenda for effective governance and management of wetlands all over the world.

Nutrient elements especially phosphorus play key role in eutrophication and associated degradations. Qiu *et al.* have reviewed the hitherto less appreciated role of phosphorus transfers from decomposing litters in far off catchment areas in wetlands of Western Australia. Carbon accumulation is another important function of wetlands and Jan Kvet *et al.* have reviewed this aspect by the macrophytes of standing water on a global scale. Another problem area is of heavy metals and R.D. Tripathi *et al.* have reviewed the role of aquatic macrophytes in bioremediation of arsenic in polluted waters.

Remote sensing and geospatial technology are new tools used in wetland researches. Masood *et al.* have explained with the help of findings obtained through remote sensing as to how the once beautiful Hokersar lake of Kashmir is fast degrading due to pollutants reaching from remote catchment areas. Pattanaik *et al.* have made use of landsat multispectral scanner, thematic mapper, linear imaging, self scanner etc. in their studies of conservation of Mahanadi delta wetlands in Orissa. Useful data so obtained have helped in increasing the total cover of Mangrove forest. Loktak lake, a Ramsar site, has been studied using geospatial technology by Sunita Devi *et al.* and found extensive floating islands formed by mass of entangled organic matter. One very large floating island is Keibul Lamjao National Park where an endangered species of deer is found. Angom and Gupta have described the productivity and turn-over of this floating National Park.

Wetlands of Kashmir are the home of rich biodiversity of flora and fauna and Pandit has described and reviewed this aspect at great length. Fishes are the most valuable food obtained from all kinds of wetlands. How best a high level of fish production can be maintained sustainably in India has been reviewed by Sinha and Jha. They have discussed the related ecological issues and conservation methods in context of Chilika, Pulicat, Vembanad and Kolleru wetlands. B.D. Tripathi *et al.* have described the physico-chemical and biological characteristics of the Surhatal wetland in U.P.

Ozone depletion has enhanced the UV-B radiations at the earth's surface. Sinha *et al.* have explained in great details largely based on their original work the adaptive mechanisms in cyanobacteria and higher plants to counteract against UV-B stress.

Ecotones between land and aquatic systems are ecologically very important tension zones with a variety of edge effects. Ambasht and Ambasht have reviewed the concepts and characteristics of different

ecotones using several case studies. Ecotone vegetation effectively controls soil erosion, water runoff and a nutrient movement as illustrated by the works of Ambasht and his students.

I thank all the contributors of papers and reviews who have kindly written on specifically requested topics at a short notice. Authors are responsible for the contents of their papers. As per norms of the Academy proceedings, all papers were peer reviewed. I thank the referees for their suggestions so I am particularly thankful to Prof. B.N. Dhawan, Chief Editor, Prof. G.K. Srivastava, Managing Editor and Dr. V.C. Srivastava, Technical Editor for their substantial help. I also feel pleasure in expressing my grateful thanks to the Academy's Executive Secretary Dr. M.S. Sinha and Assistant Executive Secretary Dr. Niraj Kumar for extending facilities and suggestions from time to time. Further I record my grateful thanks to Prof. S.P. Singh, Prof. R.K. Asthana, Dr. P.K. Ambasht, Dr. C.P. Kushwaha and Dr. N.K. Ambasht for their help at the computer and e-mails.

R.S. AMBASHT

Editor

PROCEEDINGS
OF THE
NATIONAL ACADEMY OF SCIENCES, INDIA
2008

VOL LXXVIII SECTION-B SPL. ISSUE

Wetland ecology : An overview

R.S. AMBASHT

Professor Emeritus, Banaras Hindu University; 97 Jawaharnagar Extension, Varanasi-221010, India.

e-mail : rsambasht@yahoo.com

Abstract

Wetlands are now drawing world attention of ecologists, environmental scientists, hydrologists, rural and urban planners, industrialists and everyone else connected with water quality and human health. Wetlands include all kinds of lentic and lotic fresh, brackish and saline water bodies, peats, bogs, marshes, rice fields and tidal belts upto a water depth of 6 metres. While the green belts are regarded as 'lungs', the wetlands are regarded as 'kidneys' of natural landscapes as they play key role in water purification, discharge and recharge of water stocks, etc. The wetland embankment vegetation on the river corridors and around lakes are great conservers of soil, water and dissolved nutrients which reduce upwelling of river and lake beds and arrest eutrophication and associated hazards and rise in biochemical oxygen demand.

Key words: wetland types, Indian wetlands, conservation, wetland ecology

सारांश

आज आर्द भूमि, विश्व के परिस्थितिकीय एव पर्यावरण वैज्ञानिकों, जल वैज्ञानिकों, ग्रामीण तथा शहरी आयोजकों, उद्योगपतियो तथा जल की गुणवत्ता तथा मानव स्वास्थ्य से संबद्ध हर किसी व्यक्ति का ध्यान अपनी ओर खीच रही है। आर्द्र भूमि मे सभी प्रकार के बहने वाले और स्थिर जलाशय, मृदुल, खारे तथा नमकीन जल स्रोत, दलदल, दलदली भूमि, कच्छ, धान के खेत और ज्वार–भाटे की पट्टी जिसमे पानी की गहराई ६ मीटर तक हो, सम्मिलित किये जाते हैं। जबकि हरित पट्टी 'फेफडे' के रूप में मान्य है, आर्द्र भूमि प्राकृतिक भूक्षेत्र के 'वृक्क' के रूप में जानी जाती है क्योंकि यह जल के शुद्धीकरण और जलभण्डारो के विसर्जित तथा पुर्नजीवित होने से सबंद्ध है। नदी के गलियारो तथा झीलो के चारों ओर की आर्द भूमि की तटबंध वनस्पति मृदा, जल और घुले हुये पोषकों की सरक्षणकारी है, जो नदी तथा झील के तलो को अच्छी तरह बनने नही देती, यूट्राफिकेशन तथा सबद्ध आपदाओं को रोकती है और जैव रसायनिक आक्सीजन अर्हता को बढाती है।

सांकेतिक शब्द : आर्द्र भूमि के प्रकार, भारतीय आर्द्र भूमि, संरक्षण, आर्द्र भूमि

Introduction

In recent years wetlands have attracted attention of ecologists, environmentalists and nature conservation scientists all over the world. There is a worldwide effort by most of the governments and several non-governmental organizations like the World Conservation Union (IUCN). The Ramsar Bureau, the World-Wide Fund for Nature (WWF) (Switzerland), the wetland wing of the International Association of Ecology (INTECOL), the United Nation's Environmental Programme (UNEP, Kenya), the International Lake Environment Committee (ILEC) Foundation (Japan), the Wetland International (The Netherlands) etc. The Government of India has a special division on wetlands in the Ministry of Environment and Forests (MOEnF). The MOEnF has just organized the 12th World Lake Conference designated as Taal 2007 at Jaipur, India (28 Oct. to 2 Nov. 2007). Wetlands which are water saturated are covered by shallow water bodies of all sizes and shapes, together accounting for 7 to 8 million km^2 of land surface. Furthermore a huge segment of wetlands is constituted by rice fields. Because of the excellent combination of abundant light, moisture

and suitable temperature, wetlands have a relatively higher primary production (1000 g C m^2)[1] and better biodiversity. They act as nature's bowl of speciation.

Wetland ecosystems have evolved over long years as a holistic biosystem of organisms and environmental complexes. Both the living and non-living components have evolved together as tightly fitting interdependent components as a unit. But unlike forests, deserts, grasslands and savannas, the wetlands, in the geological time scale are transitory. The rivers, lakes, peatlands, lagoons, etc. have been repeatedly formed, disappeared and again formed in recent geological periods, while man is one of the most recent creations of nature. For a long period of human history, mankind did not alter natural habitats including the wetlands. Only recently, when man became modern agriculturist, industrialist and technologist, he began disturbing the natural systems and wetlands have suffered the most. Only upto very recent past, mankind always looked for some site near perennial or permanent water source for settlements and developing villages and cities on their bank. They also dug ponds and built tanks to store water for dry seasons. Wells were dug to supplement irrigation and domestic water supply. But in recent decades the rural and urban wetlands too have been filled up and destroyed. Wetlands are exposed to multi pronged anthropogenic forces which have caused their widespread degradation and destruction. Many of the wetlands are losing their physico-chemical and biological characteristics, including biodiversity, integrity and individuality. Heavy deposition of silt load from surrounding uplands cause upwelling and reduction in water storage capacity. Inflow of nutrient from agricultural lands are responsible for eutrophication and of pesticides into biological magnification of their concentration along trophic level organisms by hundred and thousand folds. Organic matter load from municipal sewage is responsible for a high biochemical oxygen demand (BOD) and death of fishes. Naturally, because of high economic losses due to ecodegradation the problems have drawn attention of ecologists all over the world and a number of ecologists[2 to 16] have reviewed ecorestoration of different aspects of wetlnds. From the IUCN, a volume written by Dugan[17] on wetland conservation and an edited volume by Stafford and Maltby[18] have appeared recently.

One can overview the subject of wetland ecology first by describing what wetlands are, the definitions and the main types of wetlands and the hotspots of the subject. Keeping these in mind, experts in the field have been selectively invited to review these aspects as well as to highlight their own research findings.

Wetlands Defined

Wetlands are usually referred for marshy or swampy habitats, usually transitional between land and water bodies. But in modern ecological literature the meaning and coverage of the term 'wetland' has undergone tremendous modifications. The basic features are waterlogged or shallow water covered lands with stationary (lentic) or flowing (lotic) water and inhabited by animals and plants adapted to hydric conditions. They are both natural and man-made or a combination of both. They can be of fresh, brackish or saline water. Cowardin *et al.*[19] have defined wetlands as, "*land where the water table is at or above the land surface for long enough each year to promote formation of hydric soils, and support the growth of hydrophytes*". This definition has been fairly acceptable to most workers. A somewhat modified definition of the U.S. Army Corps of Engineers quoted by Smith[20] is, "*those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs and similar areas*". These definitions are silent about perennial nature and depth of water column up to which aquatic ecosystems could be grouped under wetlands. Looking to these and other shortcomings, the Ramsar Bureau[21] (headquarters at Gland, Switzerland) after reviewing all the existing definitions have given a most agreed definition, "*Areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt including areas of marine water, the depth of which at low tide does not exceed six metres*". This definition greatly broadened the meaning of wetlands to include coastal mangroves, saline backwaters, big brackish lakes and river corridors and rivers excluding very deep zones. Even deeper water bodies which are regarded as wetlands for the shallow zones on margins and the otherwise deeper zones during summer when water level goes down and wetland water covered area is considerably reduced. To continue the momentum of work in wetland ecology and to commemorate the February 2, 1977 Ramsar meeting, this day of February 2 is observed every year as the World Wetland Day.

Kinds of Wetlands

Wetlands are divided into (1) Freshwater and (2) salt rich water. Freshwater wetlands are again divided into two types, the *lentic* or standing (*Lentis* meaning calm) and *lotic* or flowing (*Lotus* meaning washed). Salt rich wetlands have varying quantities of sodium chloride dissolved in water and they are divided into two categories: (1) brackish like the coastal back waters, estuaries, lagoons, salty marshes and inland saline lakes, and (2) saline sea shores, sheltered bays, tidal belts, mangroves and some coral reefs. Visiting and receding tides greatly alter the water level and area of submergence. These salty wetlands are ecologically as well as economically of great importance. They not only harbour rich diversity of trees, shrubs, herbs, fishes, oysters, shrimps but also large mammals including the Royal Bengal Tiger in Sundarbans. Freshwater wetlands are primarily divided into (1) *lacustrine* or lakes, (2) *riverine* or river corridor and river controlled lakes and flood plains and (3) *palustrine* or marshy nutrient rich swamps, usually saturated by the subsurface ground water bearing plants like *Typha* and *Papyrus*. Swamps and peatlands cover more than half of the tropical wetlands. But globally the northern hemisphere boreal belt covers maximum wetland area. Rice fields also fall in swamp category and cover[2] about 1.5 million km^2. Extensive swamp forests occur all over the world and *Taxodium* trees dominate in the Amazonia of South America.

Dugan[17] in his book on wetland conservation has classified wetlands into seven types namely (1) estuaries, (2) coastal wetlands, (3) flood plains, (4) freshwater marshes, (5) lakes and ponds, (6) petlands and (7) swamp forests.

Lacustrine wetlands are both natural and man-made. Three categories of lakes *tectonic*, *volcanic* and *glacial* originate on rocky base without much silt or vegetation. Geological faultings create deep to shallow creeks which get covered with water. After volcanic activities in geological times and recent past, the craters and flowing lava have generated lakes. These may be small to very large with their own floral and faunal characteristics. Glacial lakes develop due to falling of the chunks of ice or by gradual movement of glaciers that create depressions and fill them with water as ice melts. In mountainous terrains there are natural high altitude wetlands, and some of them in extremely cold climates have warm to hot water through hot springs. These are of much importance to local and tourist populations. Rivers create wetlands and lakes due to meandering or change of their course. Such lakes are called ox-bow lakes (e.g. Surhatal wetlands in Ballia, U.P. (please see plate 1). Man made wetlands are: (1) aquaculture water bodies for raising fishes, culture of pearls (oysters) and producing prawns and shrimps. (2) Agricultural farm ponds and irrigated rice fields so managed as to hold water for a few months; (3) salt pans for harvesting common salt, (4) wetlands created by industrial, mining and excavations of clay for bricks. Multipurpose dams feed water to numerous smaller water storages and irrigation canals. All categories of natural and man-made wetlands are the breeding places of millions of migratory birds of all kinds. Most of such visiting birds like ducks, cranes, flamingoes, egrets, lapwings are protected by law but are hunted for human consumption on a very large scale.

There are many different kinds of names designated to distinguish different wetland types. Grass dominated wetlands are *wet meadows* and *wet prairies* of North America. *Vernal pools* are periodically flooded wet meadows in Mediterranean climate. *Sloughs* are shallow water courses and lakes in USA. Shallow water covered forests are called *swamps* and *fens*. Salt laden salt marshes are also swamps. The European deltaic wetlands are called *lagoons*. In Australia they are called *billabong*. Wetlands with accumulated semi decomposed plant residues are known as *peats*. Acidophilous peats with poor inflow and outflow of water are known as *bogs* while with faster water inflow-outflow are called *fen*. *Moor* is also European peatland type of wetland. In Canada and Alaska the *muskegs* are a kind of peat, salt rich coastal wetlands are *mangroves* which support shrubs and trees of specialized adaptations (pneumatophores, vivipary) and yield rich timber for charcoal and other plant parts for numerous medicines. *Reed swamps* producing grasses are good source of paper pulp.

Important Global and Indian Wetlands

The Denube delta wetlands with floating marshes extend over 6000 km^2 and produce *Phragmites* plants used in paper industry. The Volga river delta near Caspian sea is even bigger covering 19,000 km^2. This is the world's largest inland delta and the richest site of water birds of all kinds. It is responsible for huge tourism of the area[5]. Wetlands around Baltic sea especially

Matsalu Bay is spread over 500 km^2 flocked by swans, mallards, coots, cranes, pintails etc. In some of the above wetlands, large herds of horses and bulls roam freely. Dutch people have managed and created huge wetlands and use them profitably for bird watching sites. Africa is by far the richest continent in preponderence of wetlands. The *Sudd Swamps* are spread over 4000 km distance[20] in the Lower rift valley (Nile river). Nile watershed accounts for 3 x 10^6 km^2. The compilation of Serruya and Pollingher[22] reveal how huge these lakes are. The dimensions in terms of volume of water they contain for African lakes in terms of x 10^6 m^3 is for L. Victoria, 2,700,000 x 10^6 m^3, L Nasser, 1,57,000 x 10^6 m^3, L. Aswan 1300 x 10^6 m^3, L. Kiwu 583,000 x 10^6 m^3, L. Tanganyika 23100,000 x 10^6 m^3, L. Kariba 157000 x 10^6 m^3, etc. Other lakes and reservoirs deserving mention are L. Poopo 200,000 x 10^6 m^3 and L. Titicaca 893000 x 10^6 m^3 of South America, L. Nicaragua 80,000 x 10^6 km^3 of Central America. In S.E. Asia are Bhakra 80,000 x 10^6 m^3, Chilika 2000 x 10^6 m^3, Great lake of Kampuchea 80,000 x 10^6 m^3.

The largest swamp forests in the world are in South America Amazonia which together with swamp savannas cover 300,000 km^2 area. The Pantanals are very extensive wetlands of Argentina and neighbouring countries covering an area of 140,000 km^2. Many of the extensive wetlands around the world have thick vegetation and rich biodiversity of animals. Some of them are not easily accessable and their inner or core areas are least disturbed by man. They need to be protected and maintained for their ecological integrity and natural biota.

Indian wetlands have been listed[23] by the Wetland unit of the Ministry of Enviroment and forests. Ambasht and Ambasht[24] have reviewed their ecology and ecorestoration aspects. The country is rich in both the natural and man-made wetlands of *lacustrine, riverine* and *palustrine* types. The entire country is beset with water bodies of different sizes and kinds ranging from village and farm pools, ponds and lakes to extensive flood plains, swamps, lagoons, coastal low-lying wetlands, estuaries, deltas, back waters and ox-bow lakes. Excavation of surface soil for mining and taking soil for brick kilns also have created small wetlands. The country is also rich in high altitude lakes in Kashmir, Ladakh, Himachal Pradesh, Uttarakhand, North Bengal and the North-Eastern States as well as on the hills of South India. The country being a signatory of the Ramsar convention has designated some wetlands as Ramsar sites. The first five Ramsar Indian Wetlands are the (1) *Keoladeo National Park* (2873 ha) at Bharatpur Rajasthan known for rich diversity of migratory birds; (2) the *Chilika* wetland (116,500 ha) in Orissa, famous for birds, fishes and prawns and due to great conservation efforts, it received Ramsar award for restoration; (3) the *Sambhar* lake (19,000 ha) in Rajasthan, known for sambhar salt, numerous salt pans and sandy saline flats; (4) the *Loktak* wetland system (28,890 ha) in Manipur known for its plant and animal diversity, floating plant islands called *phundi* and (5) the *Wular* lake of Kashmir known for abundance of *Salix* trees (Willows). During the course of time a few other important wetlands which need urgent ecological conservations have been included in the Ramsar list. These new Ramsar sites are *Vambanad* coastal backwaters of Kerala, (rich in fish fauna), *Bhoj* upper lake of Bhopal in Madhya Pradesh, *Chandratal* and *Renuka* high altitude sacred wetlands in Himachal Pradesh, *Tso Moriri* a high altitude brackish water lake in Ladakh, *Pong dam* or Maharana Pratap Sarovar of Himachal Pradesh, East Kolkata wetlands, and Harike wetland at the confluence of rivers Ravi and Beas in Punjab.

Other important Indian wetlands *Koleru* (90,000 ha), *Srisailum* (61,700 ha) and *Kajam* (25,00 ha) in Andhra Pradesh; natural wetlands of Pakhui (20,000 ha) in Arunachal Pradesh, Beel wetlands of Golpara and Kamrup swamps (numerous of 100-1000 ha sizes) and Kaziranga wetland sanctuary (278,500 ha) in Assam. In North Bihar the entire landscape is swampy and full of ponds and lakes of which Kabar is famous for rich biodiversity of plants, fishes and flocks of migratory birds during the winter season. In Jharkhand state *Topchanchi* (12,800 ha) is natural and *Maithon* (10,700 ha) is man made wetland. *Nalsarovar* (18,400 ha) in Gujarat, salt marshes of Saurashtra (52000 ha) and The *Great Rann of Kutch* (100,000 ha) the home of wild asses are noteworthy. There are over forty man made big lakes is Gujarat. *Dal lake* (1720 ha), *Anchar* (6,500 ha), Hokersar (1400 ha) are of great tourist attraction in Kashmir. In Madhya Pradesh and Chhatisgarh, *Khunta* (3,800 ha) in Bilaspur, *Kharkhara* in Durg (2,800 ha), *Harsi* (2,500 ha) in Gwalior are noteworthy. In south India, *Tungbhadra* (37,800 ha), *Almati* (79000 ha), *Bhadra* (11,700 ha), *Chamraj Sagar* (647 ha) are located in Karnataka. The state of Kerala is full of wetlands like *Kottampalli* (2500 ha), *Ashtmudi* (3, 200 ha) *Idukki* (6000 ha), *Periyar* (2500 ha). In

Fig. 1 - *Eicchornia crassipes* in an extensive patch.

Fig. 2 - Foliage of rice plants emerging above the lake water surface.

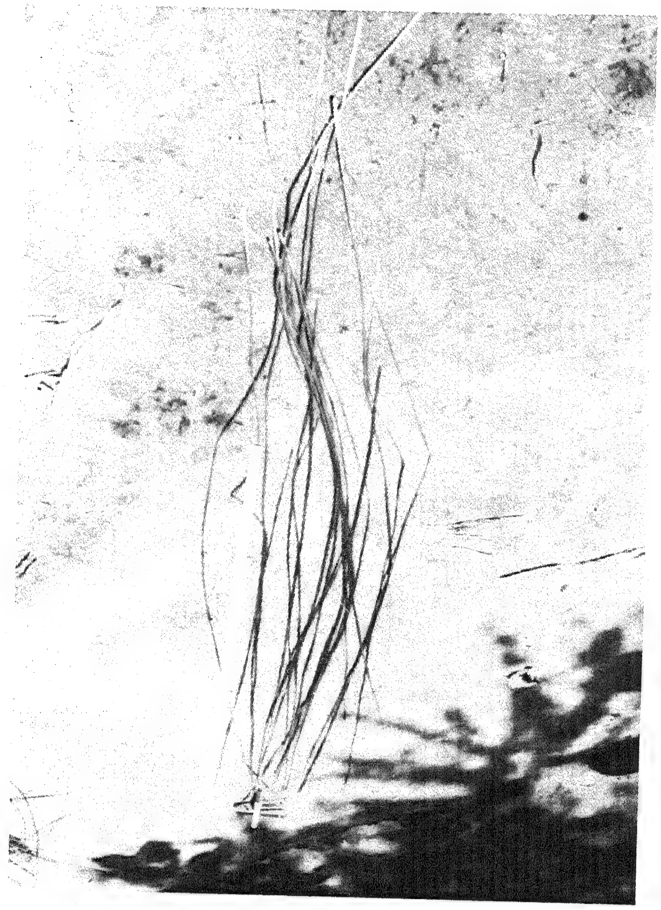


Fig. 3 - An uprooted 2.5 metre tall rice plant.

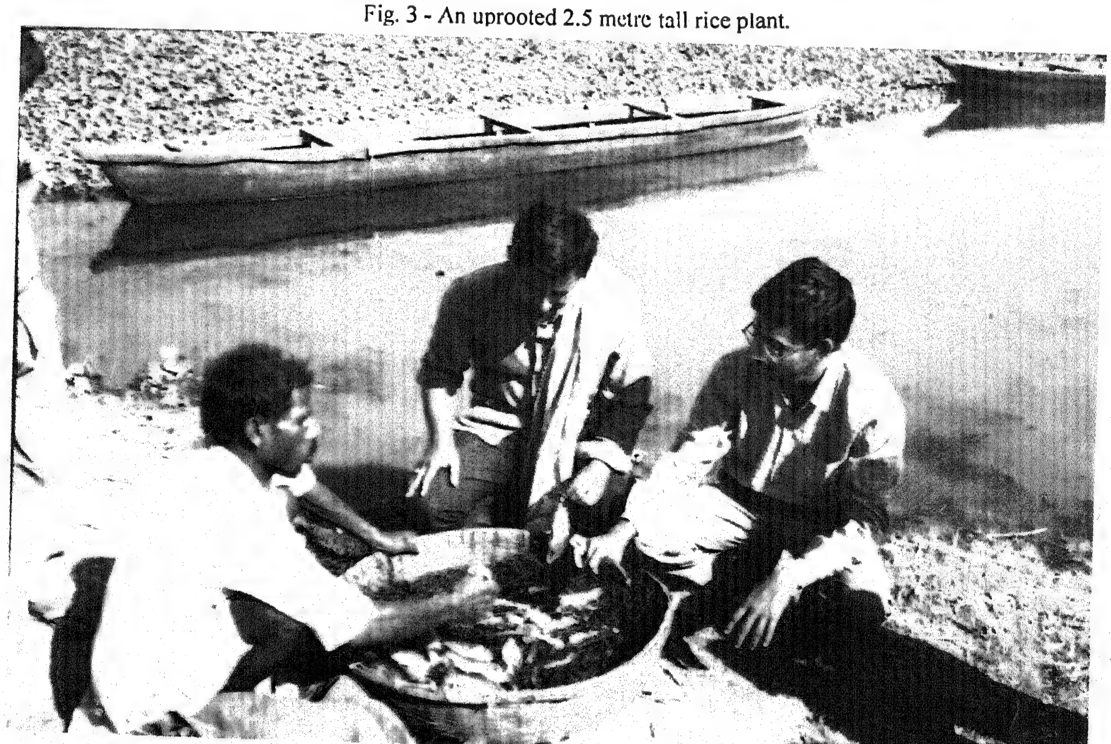


Fig. 4 - Local fisherman selling fresh fish catch at the lake margin.

Tamil Nadu is present *Pulicat* (12,000 ha). Maharashtra is also rich in natural and man made wetlands like *Mula dam* (5,400 ha), *Majalgaon* (8000 ha), *Yeladari* (10,200 ha) and *Koyana* (11,500 ha). The informations on their area are taken from the Ministry of Environment and forest compilation of the Directory of Indian wetlands[23]. There are a large a number of natural and manmade wetlands in Orissa like in Cuttack (32,000 ha), Dhenkanal (35,000 ha), Koraput (16,000 ha) and Puri (5,800 ha). Bhitarkanika is an important wetland site. There are several lakes in Udaipur (1000 ha to 7000 ha). In Uttar Pradesh, *Dudhwa National Park* is full of wetlands (8000 ha), *Surhatal* (3000 ha) *Gujartal* (200 ha), *Kalagarh* (42000 ha), *Rihand Dam* (45000 ha) are large wetlands. The entire W. Bengal is almost a potential wetland converted into terrestrial habitats for villages, cities and industries. These produce rich golden cash crop of jute and course rice. Sundarbans are among the most famous wetland formation by the deltaic flood plains of Ganga and its associated rivers in W. Bengal and Bangladesh. From tourism and religious view points, besides the above mentioned wetlands, a few that deserve mention are: *Bindusagar* (Bhubneswar), *Brahmasarovar* (Kurukshetra, solar eclipse bathing), *Ooty* and *Kodaikanal* lakes (T.N.), *Pushkar* (near Ajmer, devoted to Lord Brahma), *Nainital*, *Bhimtal* and *Vasuki*,Uttarakhand), *Manasbal* and *Mansar* (J & K), *Tsomgo* (Sikkim at 3700 m alt.). *Fatehsagar* (Udaipur), *Sukhna* (Chandigarh) and *Vastrapur* (Ahmedabad).

Ecological Hot-spot Scenario

Wetlands are usually richer in biodiversity than the terrestrial and aquatic systems. They are the cradle of speciation and close observations may reveal occurrence of ecophenes and ecotypes within the frame of species of not only wild plants but also of wild relatives of cultivated crop plants. The river corridor and lake embankment vegetation play key role in habitat stabilization and nutrient conservation against erosion and runoff. While green plants are regarded as ecosystem 'lungs' to oxygenate, the wetlands with their embankment vegetation are regarded as 'kidneys' of the landscape as they filter out pollutants and allow deeper water storages of river mainstream and of ground water free from toxic material.

The main hot-spots of ecological researches on wetlands are on biological productivity, Conservation aspects including the conservation potential (for soil and nutrients) of embankment vegetation, eutrophication and biochemical oxygen demand, biological magnification and bioremediation. Remote sensing as a tool in combination with ground truth measurements has come up very helpful. Only a few of the above aspects are briefly overviewed below while other authors have reviewed some other hot-spot topics in this volume.

Primary Production

In India, vegetation, limnology and primary production researches gained momentum with the initiation of the International Biological Programme of the UNESCO and publication of their standardized measurement method booklets. Kaul[25-26], Kaul *et al.*[27-28], Zutshi and Vass[29] have made the vegetational and biomass productivity of lakes in Srinagar (Kashmir). Ambasht and Ram[30] have made the stratified primary production patterns in Gujartal wetland and distinguished three types biomass profiles: (1) the *upright triangle type* with high biomass storage at base which gradually decreases towards the upper and surface layers of water profile. These are represented by emergents like *Eleocharis*, *Oryza* and *Vallisneria*. The next (2) *flag type* had maximum biomass concentrated on one side (windward) of water surface such as in *Nelumbo* and the third biomass profile was designated as *inverted triangle* type where high biomass was concentrated in top illuminated zone which rapidly decreased with depth as in *Hydrilla* and *Najas* community. The rate of biomass build up (primary productivity) reported by them is 20 tons ha-^{1} yr^{1} in emergent zone, 8.7 t ha-^{1} yr-^{1} in floating and 6.3 t ha-^{1} yr-^{1} in submerged zones. Their calorific contents varied between 3.28 to 4.13 kcal g-^{1} in *Oryza rufipogon*, 3.21 to 3.9 kcal g-^{1} in *Eleocharis plantaginea*, 2.8 to 3.6 kcal g-^{1} in *Eichhornia crassipes* and 3.3. to 3.7 kcal g-^{1} in *Hydrilla verticillata* dominated vegetation in Gujartal wetlands. Higher calorific values were noted in winter than the other two seasons. Ambasht[31-32] has reported biomass distribution in a Banaras Hindu University (B.H.U.) pond and reviewed Indian wetland primary production studies. In the B.H.U. pond a high biomass of 2.2. kg m-^{2} has been recorded in extensive shallow margins. In another wetland at Varanasi the production rate in *Eichhornia* was reported 6.8 t ha-^{1} yr-^{1} by Ambasht[33]. Use of remote sensing on production and actual measurements at ground (lake) level for Surhatal wetlands was also done by Ambasht[34]. Primary production for different

communities in Surhatal ranged from 6 to 8 tons ha^{-1} yr^{-1}. A highly specialized floating rice remaining submerged up to 2 metres or more produces a few leaves and entire awns above the lake surface water. These floating rice crops are often dragged by some farmers from their neighbouring position and it easily goes undetected. The calorific values of the rice varied from 3.7 to 4.1 kcal g-1. The energy conserving efficiency of Surhatal vegetation ranged between 0.28 to 0.64% of the incoming solar radiation[35].

Conservation Values

Wetland margin vegetation along river corridors and lake embankments play a real and significant role in conserving the soil against erosion, water from runoff (increasing infiltration) and conserving nutrients and arresting pollutants against their run down in the main water body. Lowrence *et al.*[36] have studied the role of riparian vegetation against non-point pollution in river watershed in Georgia, U.S.A. Destruction of ecotone vegetation is reported to reduce plant and animal population in wetlands by Triquet *et al.*[37] Streamside vegetation withholds 36-60% of annual nutrient flowing into wetlands[38].

Ambasht developed a new technique of evaluating quantitatively the conservation potential of herbaceous species in checking soil erosion, reducing runoff water and conserving nutrients from flowing across the wetland margins into the main water body. Ambasht and Ambasht[34] have reviewed this aspect in some details. The main effective soil, water and nutrient conserver species on different wetland embankments are *Saccharum benghalensis* (soil conservation value or CV=92-96%). *Cynodon dactylon* (soil CV=95-97%), *Cyperus rotundus* (soil CV 90-93%), *Leonotis nepetifolia* (soil CV=84%, water CV=50%, Nitrogen CV=71%,), *Cassia tora* (soil CV= 69%, water CV =34%). The nutrient movement is both by eroding soil and runoff water. Phosphorus runoff is more by water than soil. The conservation efficiencies for nitrogen, phosphorus and carbon for margin vegetation have been estimated by Kumar *et al.*[39,40,41,42]

Eutrophication and Biochemical Oxygen Demand

Natural wetlands are delicately balanced with respect to productivity and nutrient cycling. But even slight disturbance leads to nutrient enrichment or eutrophication. From production view point nutrient enrichment leads to fast or explosive growth of plants both the phytoplankton and the macrophytes. In the first few years it helps to produce oxygen in water and dissolved oxygen (DO) rises. Later, on death and decay, there is a preponderance of saprophytic organisms which consume all the DO in their respiratory metabolism and anoxia is created. The biochemical oxygen demand (BOD) rapidly increases. In absence of sufficient oxygen, fishes and macrophytes begin to die, leading to production of foul smelling ammonia and hydrogen sulphide and stink of decomposing fishes. This is the most serious ecological problem in the management of wetlands which receive either high nutrients as non-point runoff from surrounding uplands containing high amount of organic wastes in the untreated municipal wastes. Even soaps and detergents add considerable quantity of phosphorus, a common source of eutrophication. Freedman[43] has distinguished five categories of inland lakes on the basis of phosphorus content. These are (1) *Ultraoligotrophic* (less than 10 mg m^3), (2) *Oligotrophic* (about 10 mg P m^3), (3) *Mesotrophic* (10-35 mg P m^3), (4) *Eutrophic* (35-100 mg P m^3) and (5) *Hypereutrophic* (more than 100 mg P g^3).

Biological Magnification and Ecoremediation

A much neglected but highly significant ecological phenomenon in wetlands is of biological magnification of most of the non easily biodegradable biocides and many heavy metals. The permissible concentration is usually enforced at the application of biocides such as DDT. Biological magnification is the phenomenon of drastic increase of pesticides concentration as they pass from water to autotrophs and then again when they pass upwards of the successive trophic levels and finally, the pesticide concentration may be anywhere between upto 70,000 to 80,000 times more when it reaches the top consumer including human beings. Thus DDT when sprayed in wetlands is just sufficient to kill mosquitoes and safe for others, but its concentration rises upto 250 times in crustaceans, 5000 times in fishes and 80,000 in grebs, (a water bird). Therefore, the fate of pesticides and heavy metals ultimately harming man has to be studied fully in all such wetland pollution and management activities.

Most other hot spot aspects of current interest in wetlands including use of remote sensing, biodiversity, management of Ramsar and other wetlands, fish

production, human health, carbon and phosphorus etc. are described by invited authorities of wetland ecology in this volume.

Acknowledgements

The author is thankful to the Banaras Hindu University for facilities as a Professor Emeritus and to Prof. B.N. Dhawan, Chief Editor, Proc. NASI for inviting me to edit this volume and writing this overview.

References

1 Mitsch WJ, Mitsch RH, Turner RE. Wetlands of the old and New Worlds, ecology and management. In : Mitsch WJ, editor. Global Wetlands Old World and New. Amsterdam: Elsevier, 1994. pp. 1-56.

2. Ambasht RS, Shankar M. Rehabilitation of degraded river corridors. In : Singh JS, editor. Meerut: Rastogi Publ, 1993. pp. 191-209.

3. Ambasht RS, Ambasht Navin K. Conservation of soil and nutrients through plant cover on wetland margins. In : Ambasht RS, Ambasht Navin K, editor. Modern Trends in Applied Aquatic Ecology. New York: Kluwer Academic publ, 2003. pp. 269-280.

4. Ambasht RS, Ambasht Navin K. Conservation of wetlands-global and Indian perspectives. In : Kandya AK, Gupta A, editors. Advancing Fronties of Ecologcial Researches in India. Dehradun: Bishen Singh Mahendra Pal Pub, 2006. pp. 247-257.

5. Ambasht RS. World water and wetland resources. In : Ambasht RS, editor. Modern Trends in Ecology and Environment. Leiden: Backhuys Pub, 1998. pp. 115-130.

6. Keddy PA. Water level fluctuations and wetland conservation. In : Kusler J, Surardon R, editors. Wetlands of Global Lakes, Protection and Restoration Policies. New York: Managers Inc, 1991. pp. 79-91.

7. Cairns J. Restoring damaged ecosystems: its predisturbed condition and visible option. *The Environmental Professional* 1989; **11** : 152-159.

8. Jones CG, Laroton JH, Scharchak M. Organisms as ecosystem engineers. *Oikos* 1994; **69** : 373-386.

9. Kusler JA, Kentula ME. editors. Wetland Creation and Restoration: status of Science Washington: DC Island Press. 1990.

10. Lockwood JL, Pimm SL. When does restoration succeed. In: Weigher E, Keddy PA, editors. Ecological Assembly Rules. Cambridge: Cambridge University Press, 1999. pp. 363-392.

11. Pfadenhauer OJ, Klotzli F. Restoration experiments in middle European wet terrestrial ecosystems: an overview. *Vegetatio* 1996; **126** : 101-115.

12. Weiher E, Keddy PA. The assembly of experimental plant communities. *Oikos* 1995; **73** : 323-335

13. Pirot JY, Meynell P, Elder D. editors. Ecosystem Management: Lessons from Around the World. Gland. IUCN Pub, 2000. pp. 1-129.

14. Yan JS, Zhang YS. How wetlands are used to improve water quality in China. In: Mitsch, editor. Global Wetlands: Old World and New. Amsterdam: Elsevier, 1994. pp. 369-376.

15. Ambasht RS, Srivastava NK. Restoration strategies for degrading river and reservoir ecosystems in India. In· Mitsch WJ, editor. Global Wetland, Old World and New. Amsterdam: Elsevier, 1994. pp. 483-492.

16. Ambasht RS, Kumar R, Srivastava NK. Strategies for managing Rihand river riparian ecosystem deteriorating under rapid industrialization. In: Mitsch WJ, editor. Global Wetlands Old World and New. Amsterdam: Elsevier, 1994. pp. 725-728.

17. Dugan PJ. Wetland Conservation, a Review: Current Issues and Required Action. Gland: IUCN Pub, 1990.

18. Stafford L, Maltly E, editors. Guidelines for Integrated Planning and Management of Tropical Low land Peatlands with special Reference to southeast Asia. Gland and Cambridge: IUCN, 1998. pp. 1-65.

19. Cowardin LM, Carter V, Golet FC, La Roe ET. Classification of wetlands and deepwater habitats of the United States. Washington, DC: US Fish and Wildlife Service pub, 1979.

20. Smith RL. Ecology and Field Biology 5th Edition, New York: Harper Collins, 1996.

21. Davis TJ. The Ramsar Convention Manual. Gland: Ramsar Convention Bureau, 1994. pp. 1-207.

22. Serruya C, Pollingher W. Lakes of Warm Belts: London: Cambridge Univ Press, 1983.

23. Ministry of Environment & Forests, Wetlands of India-A Directory New Dehi MOEnF. 1990. pp. 1-150.

24. Ambasht RS, Ambasht NK, Ecology of Indian Wetlands. In: Majumdar SK, Miller EW, Brenner F, editors. Ecology of Wetlands and Associated Systems. Pennsylvania: Acad Sci Pub, 1998. pp. 104-116.

25. Kaul V. Production and ecology of some macrophytes of Kashmir lakes. *Hidrobiologia*: 1971; **12** : 63-69.

26. Kaul V. Limnological survey of Kashmir lakes with references to trophic status and conservation *International J Ecology and Environmental Science* 1977; **3** : 29-44.

27. Kaul V, Zutshi DP, Vass KK. Biomass production of some macrophytes in Srinagar lakes. In: Golley FB, Golley P. editors. Tropical Ecology with Emphasis on Organic Production Athens (USA): Univ Georgia Pub, 1972. pp. 295-311.

28. Kaul VK, Trisal CL, Kaul S. Mineral removal potential of some macrophytes in two lakes of Kashmir. *J Ind Bot Soc* 1980; **59** : 108-118.

29. Zutshi DP, Vass KK. Limnological studies on Dal Lake, Srinagar III Biological features. *Proc Ind Nat Sci Acad* 1982; **48** : 234-241.

30. Ambasht RS, Ram K. Stratified primary productive structure of certain macrophytic weeds in a large lake. In Varshney CK, Rzoska R. editors Aquatic Weeds in South-East Asia. Amsterdam: W Junk, 1976. pp. 147-157.

31. Ambasht, RS. Ecosystem study of a tropical pond in relation to primary production of different vegetation zones. *Hidrobiologia* 1971; **12** : 57-61.

32. Ambasht RS, Shardendu, Sikander M. Climate and aquatic productivity in India-state of art. In: Pandeya SC, editor. New Delhi : Proc International Conference on Biometeorology, 1983. pp. 86-106.

33. Ambasht RS. Examples of INTECOL activities in India. In : Markert B; editor. Zittau (Germany): INTECOL Pub, 1998. pp. 47-51.

34. Ambasht RS, Ambasht NK. editors. Modern Trends in Applied Aquatic ecology, New York: Kluwer Plenum Acad Publ, 2003. pp. 1-379.

35. Singh, RP. Ecological investigation of a tropical lake. Ph.D. Thesis. Banaras Hindu University, Varanasi, 1983.

36. Lowrance R, Leonard R, Sheridon J. Managing riparian ecosystem to control non-point pollution. *J Soil Water Conservation* 1985; **40** : 87-91.

37. Triquet AM, McPeek GA, McComb WC. Longbirds diversity in clearcuts with and without riparian buffer strip. *J Soil and Water Cons* 1990, **45** : 500-503.

38. Verry ES, Timmons DR. Water borne nutrient flow through an upland peatland watershed in Minnesota. *Ecology* 1982; **63** : 1456-1467.

39. Kumar R, Ambasht RS, Srivastava NK. Conservation efficiency of five common riparian weeds in movement of soil, water and phosphores. *J Applied Ecology* 1992; **29** : 737-744.

40. Kumar R, Ambasht RS, Srivastawa NK, Nitrogen conservation efficiency of five common riparian weeds in a runoff experiment on slopes. *J Environmental Management* 1992; **34** : 47-57.

41. Kumar R, Ambasht RS, Srivastava AK, Srivastava NK, Sinha A. Reduction of nitrogen losses through erosion by *Leonotis nepetaefolia* and *Sida acuta* in simulated rain intensities. *Ecological Engineering* 1997; **8** : 233-239.

42. Kumar R, Ambasht RS, Srivastava AK, Srivastava NK. The role of some riparian wetland plants in reducing erosion of organic C and selected cations. *Ecological Engineering* 1996; **6** : 227-239.

43. Freedman B. Environmental Ecology. New York : Academic Press 1995. pp. 1-606.

Proc. Nat. Acad. Sci. India, Sect. B, Vol. 78, Spl. Issue, 2008

Healthy wetlands, healthy people : How can we achieve this ideal?

PETER BRIDGEWATER

Joint Nature Conservation Committee, Monkstone House, City Road, Peterborough PE-1 1JY, U.K.

e-mail : peter@global.garden.net

Abstract

"Healthy wetlands, healthy people" is the theme agreed for the Ramsar Convention Conference of the Parties to be held in November 2008. There are strong linkages between effectively functioning wetland ecosystems and human health, and there is an important role for international governance mechanisms to promote both ecosystem functioning and resilience, and thus enhance human well-being. The role of the scientific community in determining an appropriate research agenda is key to effective governance and management of wetland ecosystems world-wide.

Key words : ecosystem services; human health; environmental governance; Ramsar convention.

सारांश

नवम्बर 2008 मे होने थाले विभिन्न दलो के सम्मेलन रामसर समागम का विषय "स्वस्थ आर्द्र भूमि, स्वस्थ लोग" है। प्रभावी रूप मे कार्यरत आर्द्र भूमि, परितत्र और मानव स्वास्थ्य के बीच सशक्त अनुबध है। अर्तराष्ट्रीय शासन क्रियाविधियो की महत्वपूर्ण भूमिका परितत्रीय कार्यकी तथा इसके लचीलेपन को प्रगतिवर्धक बनाना है जिससे मानव मात्र का कल्याण हो सके। पूरे विश्व मे आर्द्र भूमि के प्रभावशाली सचालन तथा प्रबधन हेतु वैज्ञानिक समुदाय की महत्वपूर्ण भूमिका उपयुक्त अनुसधान कार्यावलि बनाने की है।

सांकेतिक शब्द : परितंत्र सेवायें, मानव स्वास्थ्य, वातावरणीय संचालन, रामसर समागम।

Introduction

"Healthy wetlands, healthy people" is the theme agreed for the Ramsar Convention Conference of the Parties to be held in November 2008. It is worth examining how this theme can be developed under the Convention and what areas are critical for consideration by the Convention.

On Oct 4 2006, Reuters Hong Kong ran this release:

While every human death from bird flu commands widespread attention, some experts are urging the world not to forget killer diseases such as tuberculosis and HIV/AIDS, which claim millions of lives each year.

More effort must be put into preventing these diseases, and vaccines -- once they are ready -- must be made available to the poorest nations, which suffer most from these illnesses.

"Tuberculosis, HIV/AIDS are high up in terms of infectious diseases. We tend to forget childhood diarrhoea and respiratory infections, they are very important," said Georg Petersen, World Health Organisation's representative in Indonesia.

Tony Nelson, a paediatrics professor at Chinese University in Hong Kong, fears that bird flu -- which has killed at least 144 people worldwide since late 2003 -- is taking too much attention away from other very pressing diseases.

Many health experts fear the H5N1 bird flu virus might mutate and pass easily among people, triggering a pandemic that could kill millions worldwide.

"Things like SARS, avian flu are high-profile and get a lot of media attention but in terms of global deaths, it is a small percentage. The reason why we are afraid of bird flu is because it affects us personally in the rich world," Nelson said.

"If you are a policymaker in a rich country, you don't really worry about rotavirus because it is viewed as relatively mild," he said, referring to the leading cause of diarrhoea in infants and young children, killing 500,000 of them a year.

These deaths occur mostly in poor and developing countries, where health services are not always accessible.

Fear from unknown diseases which sound potentially life threatening to western city inhabitants

is a driving motive for all kinds of knee-jerk demands for environmental management; resulting in this case in enormous culling of domestic bird stocks, attempts to drain wetlands, and threats to cull migratory birds - all on flimsy evidence. The Ramsar Convention Conference of the Parties in 2005, for the first time in the Conventions' history, discussed and passed an emergency resolution on this issue[1] simply to try and provide a better balance for ecosystem actions.

The World Water Development Report[2] notes;

"Healthy freshwater ecosystems are essential for the maintenance of biodiversity and human well-being. We depend upon freshwater ecosystems for our food security and a wide range of environmental goods and services. Freshwater biodiversity is extremely rich, with high levels of endemic species, but also very sensitive to environmental degradation and overexploitation. Often also called inland waters, these ecosystems comprise a range of highly productive habitats containing a significant proportion of freshwater.

In many areas, freshwater ecosystems and species are deteriorating rapidly, often faster than terrestrial and marine ecosystems. This is having an immediate impact on the livelihoods of some of the world's most vulnerable human communities. Effects include reduction in food protein levels, clean water and potential income generation and the undermining of poverty reduction strategies." And again: "The state of human health is inextricably linked to a range of water-related conditions: safe drinking water, adequate sanitation, minimized burden of water-related disease and healthy freshwater ecosystems. Urgent improvements in the ways in which water use and sanitation are managed are needed to improve progress towards meeting the Millennium Development Goals (MDG's) related to human health."

Concern about health and the environment is essentially concern about the relationships which exist between people and the rest of the biosphere and while there have been isolated successes; people have generally handled these relationships poorly. The need to integrate more fully the goals of conservation and ecosystem management and health ethics for a sustainable society is becoming ever clearer[3]. The quality of any living system cannot over time exceed the quality of the environment in which it is found. Of course this is a process which is subject to many feedback processes: in today's terminology the drivers of ecosystem change. The Millennium Ecosystem Assessment[4] defined a new conceptual framework[5], placing emphasis on the management of the environment to deliver ecosystem services, and through those services to enhance human well-being. Well-being is more than simply human health, and reflects a more holistic approach. But to deliver better human health outcomes, we need to have healthy ecosystems - i.e. ecosystems which continue to deliver services to people and the biosphere.

From the perspective of human health, wetlands (as defined by the Ramsar Convention[6]) have a real identity crisis. They are often seen simply as human health hazards, with malaria, bilharziasis, and a whole host of other parasitic diseases typically associated with them. Two centuries ago, the dank surroundings of lakes and worse swamps were enough to provoke people into believing that to be simply close to such a landscape feature was to risk catching a fever. And then came Avian Flu, to give it its popular title, with all its attendant hysteria and muddle-headed reaction described above. So should we just drain lakes and wetlands, or cover them with a blanket of DDT? Or are there other approaches?

Healthy Ecology

Firstly we need to look at the synergy of health, synergy of disease, and the ecosystem context of health. Wetland biodiversity and ecosystem services are of crucial importance to people in every country. On health, 75% of the world's population depend primarily on traditional medicines, which are mainly gathered from the wild - with wetlands providing many examples of traditional medicines and prophylaxes. In addition, wetland biodiversity underpins cultural and spiritual values, and provides the basis for the way in which social institutions, religious beliefs and traditional knowledge have evolved[7].

Human health is dependent on biodiversity and on the natural (or healthy) functioning of ecosystems. Considering people as part of nature, who must learn to live in balance with other species and within its ecosystems, leads to a realisation that biodiversity and human health are different aspects of this same issue. Enhancing discussions about development and environment in the more personal terms of promoting human health through ecosystem health, is an effective way to help people understand the linkage between biodiversity

and development. A wide range of wetland ecosystem services promote human health. Examples include provision of medicinal remedies; filtering nutrients and other substances ; protection against flooding, storms and erosion; breaking down of waste and recycling of nutrients; sequestering carbon that mitigates global climate change as well as stabilisation of local climates; and maintenance of the water cycle[8, 9].

The concept of an "ecological public health" has emerged in response to a range of new health issues and risks. In effect a shift in risk patterns - arising from a new set of global ecological or environmental risks. Many of the new ecosystem threats, from ozone depletion to climate change phenomena to increased threats from tsunamis pose a risk to health, and thus a need to understand the interdependence of people, their health and physical and social environments. Understanding the multi-dimensional nature of the environment and its attendant changes is key to changing the negative relations that humans develop in interaction with their environment. In the end we need to have the ability to relate health of individuals to the health of ecosystems and landscapes in which they live. International legal instruments like the Ramsar Convention can play a key role here.

A new (ecological) public health approach would move from reliance on behavioural epidemiology and surveillance to a more environmental and social approach, using an ecological paradigm as the organising framework. Links between ecosystem balance and human health are clear. The continued loss of biodiversity and subsequent reduction in the delivery of ecosystem services equals decline in health levels. Here we return to the concept of ecosystem services and their indispensability to the well-being and health of people everywhere. The causal links between environmental change and human health are complex because often they are indirect, displaced in space and time, and dependent on a number of modifying forces. For example, many aspects of the world's hydrological (water) cycle are regulated by the natural functions of ecosystems and associated geophysical processes (such as evaporation and the functioning of the climate system).

Human interventions in watersheds, lakes and river systems take many forms - deforestation, farming, irrigation, river damming and extractions from subterranean aquifers. Wetlands play a crucial role in the filtering of fresh water, including the removal of various chemicals and potentially toxic elements (e.g. heavy metals such as cadmium and lead). But it is the provision of fresh water for which wetlands are so important in ensuring human health. Fresh water is used for growing food, drinking, personal hygiene, washing, cooking and the dilution and recycling of wastes. Water scarcity jeopardizes food production, human health, economic development and geopolitical stability. Globally, the availability of water per person has declined markedly in recent decades. One third of the world's population now lives in countries experiencing moderate to high water stress. This fraction will continue to increase as both population size and per capita water demand grow - reflecting the escalating use of fresh water for irrigated agriculture, livestock production, industry and the requirements of wealthier urban residents.

According to the first World Water Development Report[10] over 1 billion people lack access to safe water supplies; 2.6 billion people lack adequate sanitation. This has led to widespread microbial contamination of drinking water. Water-associated infectious diseases claim up to 3.2 million lives each year, approximately 6% of all deaths globally. The burden of disease from inadequate water, sanitation and hygiene totals 1.7 million deaths and the loss of more than 54 million healthy life years. Investments in safe drinking-water and improved sanitation show a close correspondence with improvements in human health and economic productivity. Every day each person needs 20-50 litres of water free from harmful chemical and microbial contaminants, for drinking, cooking and hygiene. The growing challenge of providing this basic service to large segments of the human population is highlighted by one of the United Nations Millennium Development Goals, MDG-7, which calls for halving by 2015 the proportion of people without sustainable access to safe drinking-water. Currently, this goal is far being able to be achieved, especially in Africa.

Recently, there has been an upturn in the rate of emergence or re-emergence of infectious diseases. Factors contributing substantially to this trend include: intensified human encroachment on natural environments; reductions in biodiversity (including natural predators of vector organisms); particular livestock and poultry production methods; and increased long-distance trade in wild animal species (including as food). Further contributors include: habitat alterations that lead to changes in the number of vector breeding sites or in reservoir host distribution; niche invasions or interspecies host transfers; human-induced genetic

changes of disease vectors or pathogens (such as mosquito resistance to pesticides or emergence of antibiotic-resistant bacteria); and environmental contamination by infectious disease agents[11].

Schistosomiasis, also known as bilharziasis, is endemic in 74 developing countries, infecting more than 200 million people. Over-fishing of cichlid fish in Lake Malawi resulted in the decrease of a predatory fish species and subsequently in an increase in a species of snail that is the intermediate host for *Schistosomiasis haematobium*. This clear link between use of biodiversity in an unsustainable way paved the way for an outbreak of Schistosomiasis at Lake Malawi in 1992. Of course many examples are less clear-cut and obvious, due to the complex interlinkages with ecosystems. Deforestation in tropical forests has considerably contributed to the spread of malaria by providing wetland habitats such as stagnant pools, which allow rapid growth of larval *Anopheles* mosquitoes and increase their potential for reproductive success. Similarly, badly managed wetlands can be a continual source of re-infestation of *Anopheles*. And here the synergies with changes from the effects of climate change are also important to consider.

Water-related diseases affect over 2 billion people a year. Providing clean water and sanitation to poor communities would take pressure off their need to unwisely use wetland ecosystems, reduce waste flows and improve freshwater and coastal water quality.

Many of the people and sites affected adversely by ecosystem changes and are highly vulnerable - and ill-equipped to cope with further loss of ecosystem services. Ecosystem changes, with an increasing risk of non-linear changes in ecosystems, including accelerating, abrupt and potentially irreversible changes are likely to have a catastrophic effect on human health. The increased likelihood of these non-linear changes arises, in part, from the loss of biodiversity and growing pressures from multiple direct drivers of ecosystem change.

Governance Mechanisms

The extent of communication between environmental and human health professionals has, in some instances, been excellent. The 1999 Protocol on Water and Health under the UNECE's Convention on the Protection and Use of Transboundary Watercourses and International Lakes, can be taken as an example of success[12]. The main aim of the Protocol is to protect human health and well being by better water management, including the protection of water ecosystems, and by preventing, controlling and reducing water-related diseases. The Protocol is the first international agreement of its kind adopted specifically to attain an adequate supply of safe drinking water and adequate sanitation for everyone, and effectively protect water used as a source of drinking water. This activity, spread more widely, will help the world achieve the Millennium Development Goals[13], especially Goal 7. To meet these aims, its Parties are required to establish national and local targets for the quality of drinking water and the quality of discharges, as well as for the performance of water supply and waste-water treatment. They are also required to reduce outbreaks and the incidence of water-related diseases. But how should we react to water-borne disease? Our natural reaction is to fight each disease as it appears a one to one battle. Yet over time it is clear this approach has limited successes and is costly economically and ecologically.

In May 2002, at a speech at the American Museum of Natural History, the UN Secretary-General outlined a so-called WEHAB initiative, by identifying five major areas for the World Summit on Sustainable Development, areas where concrete results are both essential and achievable. The WEHAB areas were: Water, Energy, Health, Agriculture, and Biodiversity. The initiative recognised for the first time, the critical importance of biodiversity in delivering services in each of the other sectors. And by including Water, biodiversity, health and agriculture it also brought together key concerns for the Ramsar Convention. Although a WEHAB Working Group was established, and published *A Framework for Action on Biodiversity and Ecosystem Management* in August 2002, this initiative has largely disappeared from view, and even the url no longer works! Crucially, the WEHAB working group paper highlighted the need to shift focus from the proximate causes of biodiversity loss to the underlying causes. It focuses on two key action areas: integration of biodiversity - and principles of sustainable development - in country development programmes and economic sectors; and halting the loss of biodiversity and restoring, if possible, biodiversity in degraded areas, as part of reversing loss of environmental resources. Importantly, reflecting the close linkage between the WEHAB framework and the MDGs, the two Action Areas in this WEHAB paper are built upon and consistent

with targets of MDG 7 to 'ensure environmental sustainability.' The action frameworks provide indicative targets or milestones, with examples of activities - a 'menu' for further development of activities. Linkages between biodiversity and the health aspects of development are still little understood[14].

Ideally we should be building on biodiversity linkages evident between the five WEHAB areas. And yet, vital though it seemed at the time, WEHAB has not found much favour since the lead-up to the Johannesburg summit. With the theme of "Healthy wetlands, Healthy people", it represents a latent framework for the wetland biodiversity community to develop and use. However, we need to develop specific strategies, tools and ways of measuring success - work being undertaken through the Ramsar Convention Science and Technical Review Panel. This will include monitoring ecosystem functions in all parts of the world and developing environmental assessment and indicators.

Human health is not just about being not sick, however. The Millennium Assessment uses rather the term "human well-being". Solving issues of poverty and management of natural disasters are critical to achieving human well-being, as recognised by the last Ramsar Conference of the Parties[15]. For the poor, food security depends to a large extent on biodiversity, through direct consumption of wild foods, wild plants for farm production, medicines, fuel, and the trading in species and products. Conversely, loss and change of biodiversity can increase hunger and food insecurity. Wetland Ecosystem degradation means less water for people, crops and livestock, lower crop yields, and higher risks of natural disasters. Nevertheless, the relationship between biodiversity and poverty is complex and not linear. This is exemplified through human - wildlife conflicts, increased mobility of pests and diseases, and introduction of invasive species, innocently or deliberately.

Wetland related agriculture is a particular area where strategies to apparently improve human wellbeing may erode biodiversity, and globally we need strategies in place to address this. Replacement of wetland ecosystems by monocultural production (e.g. low diversity rice paddies) leads definitively to loss of both biodiversity and a thus a range of ecosystem services. In addition, local people, custodians of their biodiversity, often lack access to information to the range of ecosystem services under their control, which hampers their ability to negotiate and obtain appropriate returns. The marine and fisheries sector faces specific problems, such as the lack of understanding of the functioning of tropical aquatic systems. Also, while marine fisheries have obtained great attention, island fisheries are less well known, in particular regarding the interactions with land-based productions. Inland aquaculture has risen dramatically, but can have deleterious effects on the rest of aquatic biodiversity. Invasive species also constitute a major threat to wetland ecosystems, and these effects in many cases impacts substantially on the poor.

Strategies for implementation

The World Water Development Report[9] notes that: Annually, 5-6 million people die from water-borne diseases and air pollution. One third of the world's population face water scarcity or water stress. In Africa, only 62% of the population have access to safe water. With increasing time needed to collect water, time for other basic activities including education is being reduced. In 2000, 500 million people were living in urban poverty. In Africa, between 15% and 65% of city dwellers live in poverty, with little or no access to an entire set of social and urban services that constitute decent living conditions. Urban poverty in Africa is growing faster than rural poverty. In other parts of the world, this situation has considerably improved. In India, 95% of urban people are estimated by the World Health Organization (WHO) to have access to safe water and 61% to sanitation.

This leads to the need for some key areas for implementation;

- Recognise and safeguard the key role of biodiversity and ecosystem services in water cycles

- Adopt integrated watershed management, with ensuring community involvement and employing the Ecosystem Approach

- Use biodiversity to protect water sources, and reduce treatment costs, including through:

(i) maintaining and restoring the capacity of soils for groundwater filtering

(ii) managing mountain and other upland biodiversity to safeguard water sources

(iii) establishing appropriately managed protected areas

• Use biodiversity to protect urban settlements, through the use of coastal ecosystems for coastal protection and other benefits, and through the use of flood plain wetlands for flood protection, including

(i) Maintaining freshwater food productivity

(ii) Avoiding costs and consequences of channelisation

(iii) Considering health impacts of wetland management

(iv) Using constructed wetland technologies for sanitation treatment, e.g. reedbeds.

Using biodiversity in urban contexts is particularly cost-effective, by, *inter alia*, enhancing coastal protection, reducing the need for treatment of water supplies, supplying aquatic food instead of land clearing for animal protein, reducing the need for conventional waste water treatment, and reducing health costs through providing good water quality and sanitation. The Commission for Sustainable Development (CSD) has discussed issues on water, sanitation and human settlement and retains these issues on the agenda. The thirteenth meeting of the CSD considered especially water and health issues in the context of sustainable development, and its communiqué[16] is relevant to consider within the topic of this paper.

The final communiqué, which dealt with Water, Sanitation and Human Settlement, had the members of the Commission adopting a number of points, *inter alia*, that (bold emphases mine);

▼ The policy options and practical measures for expediting implementation relating to water, sanitation and human settlements should be nationally-owned and integrated into poverty reduction strategies and/or national sustainable development strategies, whose implementation should begin by 2005, or national development plans;

▼ The JPOI goals related to water from the Johannesburg summit of 2002, and the internationally agreed development goals, including those contained in the Millennium Declaration, are complementary and an integrated approach is necessary;

▼ Investments in water, sanitation and human settlements contribute to economic growth, sustainable development, better health and reduced poverty. The achievement of water, sanitation and human settlements goals, is critical to the implementation of the three pillars of sustainable development and the achievement of all the internationally agreed development goals;

▼ Governments have the primary role in promoting improved access to safe drinking water, basic sanitation, sustainable and secure tenure, and adequate shelter, through improved governance at all levels and appropriate enabling environments and regulatory frameworks, adopting a pro-poor approach and with the active involvement of all stakeholders;

▼ Efforts by Governments to achieve the agreed goals and targets on water, sanitation and human settlements should be supported by the international community through a conducive international policy environment, including through good governance at the international level;

▼ Water, sanitation and human settlements are interlinked and complementary and should be addressed in an integrated manner, taking into account economic, social and environmental aspects, related sectoral policies and cross-cutting issues as identified at CSD-11, as well as national, sub-regional, and regional specificities, circumstances and legal frameworks, and bearing in mind that no one size fits all;

On Integrated Water Resources Management[17] specifically, the CSD urged acceleration of preparation of nationally-owned IWRM and water-efficiency plans tailored to country-specific needs, paying particular attention to economic development, social and environmental needs, supporting implementation through learning-by-doing, directed, *inter alia*, towards the following:

▼ Encouraging, where appropriate and within their mandates, the use of MEAs to leverage additional resources for IWRM;

▼ Improving water governance through strengthening of institutional and regulatory reforms, capacity development and innovation;

▼ Providing technical and management support to local authorities and community-based organizations, taking into account research, traditional knowledge and best practices, to improve water resources management within national policy frameworks;

▼ Encouraging effective coordination among all stakeholders in water-related decision making;

▼ Enhancing the sustainability of ecosystems that provide essential resources and services for human well being and economic activity in water-related decision making (here we should perhaps add the concept of ecosystem resilience is important.);

▼ Facilitating information exchange and knowledge sharing, including indigenous and local knowledge;

▼ Strengthening the prevention of pollution resulting from wastewater, solid waste, industrial and agricultural activities;

▼ Developing preventive and preparedness measures, as well as risk mitigation and disaster reduction, including early warning systems;

▼ Protecting and rehabilitating catchment areas for regulating water flows and improving water quality, taking into account the critical role of ecosystems;

▼ Involving all stakeholders, including women, youth and local communities, in integrated planning and management of land and water resources;

▼ Promoting higher priority and greater action on water quality;

▼ Supporting African initiatives in the area of water, within the framework of AMCOW, with particular reference to basin-wide initiatives in Africa;

▼ Enhancing cooperation among riparian States through relevant arrangements and/or mechanisms with the consent of the States concerned, taking into account the interests of the riparian States;

▼ Supporting more effective water demand and water resource management across all sectors, especially in the agricultural sector, by:

(i) Using efficient irrigation and rain water harvesting technologies;

(ii) Implementing irrigation projects with a focus on the poor, particularly in Africa;

(iii) Training farmers and water user associations in efficient water use and sustainable agricultural land management;

(iv) Promoting the use of waste-water for certain irrigation purposes, subject to health and environmental standards;

(v) Increasing the efficiency, and where appropriate, the use of rain-fed agriculture.

▼ Developing and strengthen national monitoring systems on the quantity, quality and use of surface and groundwater resources at national and local levels, and for measuring progress towards internationally agreed goals and targets, as appropriate, as well as for assessing the impact of climate variability and change on water resources, through the following actions:

(i) Establishing and managing water information systems;

(ii) Installing networks for monitoring water resources and quality;

(iii) Standardizing methodologies and developing monitoring indicators;

(iv) Transferring monitoring technologies adaptable to local conditions;

(v) Disseminating information to relevant stakeholders.

Several interventions in the discussions leading to this communiqué emphasized the role that the scientific community can play in providing solid science and technical background for the suite of international environmental governance mechanisms. Unified and joint action among the countries of the world, through the already existing legal and governance mechanisms, will promote better ecosystem management, therefore better ecosystem function and service delivery, and ultimately better human health.

Based on the above, a key strategy for avoiding disease and injury caused by ecosystem disruption is to implement the ecosystem approach of the Convention on Biological Diversity18. A key part of the approach is to implement adaptive management that will protect individuals and populations from the adverse consequences of ecosystem change. There is a need for a more systematic inventory, by region and country, of current and likely population health impacts of ecosystem change. Priority-setting of actions to address the health consequences of ecosystem change also should reflect the priorities and values of all those affected by the proposed actions. Like climate change, the responses to ecosystem changes include mitigation and adaptation. Mitigation implies *reducing* or *reversing* the process of change. Adaptation aims to increase the *resilience* of both social systems and

ecosystems to the impacts of externally induced changes in order to reduce the current and future human health risks. Adaptation also can be seen in a positive light, i.e. to take advantage of beneficial consequences of ecosystem change.

All of these areas involve improving our knowledge systems of the structure and function of wetland ecosystems i.e. improving the science base. Yet because of the critical importance of the cultural and spiritual benefits derived from wetlands it is not just more natural science we need, but joint programmes of research and understanding between natural and social sciences - in effect helping to understand the knowledge-policy interfaces[19] we need to improve management of wetland ecosystems, and how then they can provide for healthier human populations.

Research foci should include:

- The ecosystem impact of harvesting medicinal plants in the wild
- Documenting traditional/indigenous health knowledge while respecting and protecting the rights of the holders of this knowledge
- The origins of some disease vectors
- Economically and ecologically effective ways of using wetland systems in a semi-natural state to grow food crops for household consumption to improve diets and to reduce complete damage or destruction of natural wetlands
- Natural pest control and ways of more effectively controlling invasive species.
- Water management schemes limiting the potential spread of disease vectors such as malaria

The implementation of National Biodiversity Strategies and Action Plans, should integrate links between human health and effectively functioning wetlands

A better understanding of the ecology of wetland ecosystems will be crucial to these achievements, and this means continued and strong scientific support work is needed to underpin the political and administrative decisions. Delivering a global research agenda related to the needs of global governance and wetland management will be a major advance in promoting healthy wetlands for healthy people. Such a global research agenda could perhaps be undertaken with the leadership of ICSU, as the global focus for work under the National Academies, and the Earth System Science programmes.

References

Note: all urls were effective 22/11/2007.

1. http://ramsar.org/res/key_res_ix_23_e.htm
2. http://unesdoc.unesco.org/images/0014/001444/144409E.pdf.
3. Honari M, Boleyn T. editors. Health Ecology. London: Routledge Press, 1999.
4. http://www.millenniumassessment.org/en/index aspx
5. http://www.millenniumassessment.org/en/Framework.aspx
6. http://ramsar.org/ris/key_ris.htm#type
7. Bridgewater Peter, Arico Salvatore, Scott John

   Biological diversity and cultural diversity - nature and culture through the looking glass of the multilateral biodiversity agreements. *International J Heritage Studies*. 2007; **13** : 405-419.
8. http://ramsar.org/res/key_res_ix_09_e.htm
9. http://ramsar.org/res/key_res_ix_14_e.htm
10. http://www.unesco.org/water/wwap/wwdr1/table_contents/index.shtml
11. http://www.who.int/water_sanitation_health/resources/envmanagement/en/
12. http://www.unece.org/env/water/text/text_protocol.htm
13. http://www.un.org/millenniumgoals/
14. http://www.med.harvard.edu/chge/resources.html
15. http://ramsar.org/res/key_res_ix_01_annexc_e.htm
16. http://www.un.org/esa/sustdev/sdissues/water/water.htm
17. http://www.gwpforum.org/gwp/library/Tacno4.pdf
18. http://www.cbd.int/programmes/cross-cutting/ecosystem/default.shtml
19. van den Hove S. A rationale for science-policy interfaces. *Futures* 2007; **39** : 807-826.

Proc. Nat. Acad. Sci. India, Sect. B, Vol. 78, Spl. Issue, 2008

Role of catchment litter in wetland P cycling-recent experience from Western Australia

SONG QIU*, ARTHUR J. McCOMB and RICHARD W. BELL

School of Environmental Science, Murdoch University, Murdoch WA 6150, Australia.

**e-mail : S.Qiu@murdoch.edu.au*

Abstract

Many wetlands in south-western Australia are situated in the interdunal depressions of coastal sand dunes, and have catchments with significant native vegetation. While farming and urbanisation are common sources of nutrients, natural processes such as P release from catchment litter and its potential as a P source for these waters have rarely been investigated. Such information is important not only in understanding the wetland ecology, but also in setting restoration targets for eutrophic waters in the region. This review focuses on recent works conducted in a number of small wetlands near Perth, Western Australia, covering the issues of litter production, rates of decomposition and P leaching, subsequent interactions of leachate with soil and microbial biomass, and the mobility of nutrients. The export of P from catchment litter to wetland was estimated using a new "in-lake" method, developed to quantify P transfer through primary (atmospheric and groundwater) and secondary processes (e.g. circulation and sediment-water interactions).

Key words : catchment litter, litter decomposition, P leaching, microbial P, P cycling, seasonal wetland

सारांश

दक्षिण–पश्चिम आस्ट्रेलिया की अनेको आर्द्र भूमि समुद्र तट के बालू के टीलों के बीच के अवनमनीय क्षेत्रों में स्थित है। इनके जलग्रहणी क्षेत्रो मे महत्वपूर्ण स्थानीय वनस्पतियॉ पाई जाती है। जबकि पोषको के सामान्य स्त्रोत खेती और शहरीकरण है, कुछ प्राकृतिक प्रक्रियाये जैसे जलग्रहण क्षेत्र के कूडा कर्कट से फास्फोरस का मुक्त होना तथा फास्फोरस के स्त्रोत के रूप मे इन जलाशयों के प्रभावों पर कदाचित ही अनुसंधान हुये हैं। इस प्रकार की सूचनायें आर्द्र–भूमि की परिस्थितिकी को समझने के लिये तो आवश्यक है ही साथ ही इन स्थानों के यूट्राफिक जल के जीर्णोद्वार का लक्ष्य बनाने में भी महत्वपूर्ण है। यह पुनर्विलोकन पश्चिमी आस्ट्रेलिया के पर्थ के छोटे–छोटे आर्द्र–भूमियों पर नवीनतम अनुसधानों पर केन्द्रित है जिसमे, घास–फूस का उत्पादन, इनके निक्षेपण की दर और फास्फोरस का निथारन, निक्षालन का मिट्टी तथा रोगाण्वीय जीव मात्रा से अंतः क्रिया तथा पोषको की सचलता, महत्वपूर्ण हैं। जलग्रहण क्षेत्र के घास–फूस से आर्द्र भूमि की ओर फास्फोरस का निर्यात एक नवीन विधि "इन–लेक" द्वारा अनुमानित किया गया है। उसका विकास फास्फोरस के स्थानान्तरण का, प्राथमिक (वायुमंडलीय और भू–जल) तथा गौण विधियो (उदाहरर्णाथ परिचलन और तलछट जल की अंतः क्रिया) द्वारा परिमाण प्राप्त करना है।

सांकेतिक शब्द : जलग्रहण क्षेत्र का घास–फूस, घास–फूस का सडना, फास्फोरस का घुल कर बहना, रोगण्वीय फास्फोरस, फास्फोरस चक्र, मौसमी आर्द्र भूमि

Introduction

Many wetlands of the Swan Coastal Plain of south-western Australia have catchments with significant areas of native vegetation. These wetlands are numerous, and mostly feature poor water exchange, shallow depth, and limited open water. They potentially serve as filters or sinks which inhibit nutrient loss from the landscape during wet seasons. During the past few decades the region has seen an alarming increase in the nutrient loading and consequently the eutrophication of surface waters. The freshwater wetlands in the region are generally located in the inter-dunal depressions between coastal sand dunes, and are often P limited in relation to phytoplankton growth.

Soils in the region are built up by accumulation of marine, aeolian and alluvial sediments, and much of the upper horizons are severely leached, infertile, and typically contain low P and low organic matter[1]. The increased P in the water bodies, which has been commonly observed in past decades, has been largely attributed to human activities, such as agriculture and urbanisation[2]. Ecological studies elsewhere have shown that plant litter from fringing vegetation can serve as a primary energy and nutrient source for wetland ecosystems[3, 4, 5]. Terrestrial litter also serves as a

nutrient source for downstream waters via direct litterfall, wind, run-off and seepage[6, 7]. Such a source was reported to account for over 70% of annual soil carbon flux[8]. The amount of nutrients recycled through litterfall may vary with vegetation type, catchment cover, climate and site conditions. Wetlands in southeastern USA have litterfall of 4100 to 5820 kg $ha^{-1}yr^{-1}$, with litterfall N input of 43 to 52 kg $ha^{-1}yr^{-1}$ and P of 2.2 to 2.7 kg $ha^{-1}yr^{-1}$ [9]. In the Southern Hemisphere, nutrients turnover from litterfall was reported to be 59 to 64 kg $ha^{-1}yr^{-1}$ for N and 1.9 to 2.4 kg $ha^{-1}yr^{-1}$ for P in a rain forest in Australia[10]. In southwestern Australia, about 58 kg $ha^{-1}yr^{-1}$ N and 1.9 kg $ha^{-1}yr^{-1}$ P may be returned from karri (Eucalyptus diversicolor F. Muell.) forest sites in P-poor areas[11].

While farming and urbanisation are two common sources of nutrients, natural processes such as P release from woodland litter and its significance as a P source for interdunal wetlands is largely unknown. There is little attention to such natural sources of nutrients. Anecdotal evidence suggests there is a connection in P cycling between catchment and wetlands. For example wetland sediment, where there is an accumulation of organic materials, often exhibits higher P content than native soils. Such enrichment of sediment P has been observed in a number of wetlands studied near Perth[12]. In a study on the role of catchment litter in wetland P cycling, the authors observed increased soil P content from upland (woodland) to wetland, from 50 to up to >1000 g Pg^{-1} in the catchment of Thomsons lake[13]. The lowlying area, where there is an accumulation of tree litter, was found to have the highest soil P content. Such information appears to suggest that catchment litter has a role in wetland P enrichment, important not only for understanding the role of catchment litter as a nutrient source for local wetlands, but also for understanding nutrient conditions prior to human disturbance, which is critical in setting restoration targets for eutrophic waters in the region.

Catchment litter as a P source—a sediment perspective

In a study of a number wetlands near Perth, southwestern Australia, the authors found sediment total P content to be typically correlated with sediment organic matter (R^2 = 0.94)[12]. There is a high organic P content in sediment (average 37%), with humic-P accounting for a large proportion of total P in some lakes (up to 74%, average 20%). These data support previous findings that phosphorus associated with humic substances can be a major pool, accounting for more than half of the sediment phosphorus budget in freshwater wetlands[14, 15]. There can be two possible sources for this sediment P enrichment: 1) sedimentation of algal and plant material through internal P cycling. These wetlands are often surrounded by dense fringing vegetation, and some produce in-lake macrophytes and emergent plants, so that organic debris can be an important component of sedimentation, leading to an accumulation of humic materials on lake sediments; 2) transport of P and organic P along with organic C from external sources. Gilvin (originating from the Latin adjective 'gilvin', meaning pale yellow) is generally relevant to various heteropolycondensates of phenolic compounds (humic substances). There is evidence that gilvin is transported from wooded catchment to the wetlands[16, 17]. In 'humic-stained' waters the gilvin content (measured as g440) may reach 58 m^{-1} [18]. It is reasonable to expect nutrient transport to follow similar export pathways towards wetlands. The authors focused on studying the second possibility since it is linked to catchment litter turnover, and the relevant processes are much less known, and while internal cycling is important it can be considered as secondary processes which rely on external loading.

Litter P leaching

The authors used both field and laboratory approaches to delineate the relation between catchment and wetland processes in P cycling, and the connectivity between the two. Firstly, litterfall from common plant species were collected before the local rainy season, and examined for P leaching properties under inundated conditions. It was found that inundation of 'intact' litter for 24 hours leached 30±7.5% (95% confidence level) of the total P in litter. The leached amount increased to 46.9% of total P at 115 days of inundation. Part of the released P was incorporated into microbial biomass during the long leaching period, so modifying leachate concentrations. Using liquid chloroform 'fumigation' it was estimated that 36.2 ± 15.6% (95% confidence level) of total P leached during the 115-day inundation was in the microbial biomass pool[19]. Overall, P leaching during initial and prolonged inundation was correlated with litter Ca, Mg and total base concentration, but the initial total P concentration of litter was a good predictor of P leaching, in both short-term and prolonged inundation (R^2 = 0.80 and 0.93, $p < 0.0001$)[19].

The high P leaching rate during 24 hours suggests that P from litter, some sitting on the forest floor over much of the hot and dry summer, could produce a significant P flux from local catchments during early storm events of the wet season, and thus can be a potential source contributing nutrients to downstream wetlands. By a simple calculation the authors found the amount of P leached from litter via annual rainfall may equal the P held in the water column of shallow wetlands on an area (catchment)-to-area (wetland) bases[19].

However, rates of leaching and decomposition depend not only on litter quality but also on field conditions. Data derived under laboratory conditions may need to be further validated under field conditions. In south-western Australia, the most notable factors operating on a wetland catchment are probably those associated with seasonal rainfall and the resultant drying and reflooding conditions in seasonal wetlands. Some 90% of annual rainfall is concentrated in the winter months from May to October, which was found to coincide with the period of most nutrient loads transported to major rivers in the region[20]. The authors therefore examined leaflitter leaching and P release under field conditions over the wet season. Litter was collected from a few species common on the woodland catchment, flooded gum (*Eucalyptus rudis* Endl.), jarrah (*Eucalyptus marginata* Sm.), banksia (*Banksia menziesii* R.Br.) and blue gum (*Eucalyptus globulus* Labill.) and used to investigate P leaching in the field. These were tested in presence or in the absence of soil, and under inundated or non-inundated conditions. Results showed that litter P was primarily released to leachate during the first wet month (May to June), under either inundated or non-inundated conditions. Overall, 25.7-84.1% of total P in litter was released over the rainy months from May to November, but mostly during the 'first flush', which occurred in early May[21]. On the other hand, the leachate was highly yellow-coloured, especially during the 'first flush', which had total P concentration of 1.2-4.6 mg L^{-1} (non-flooded) to 1.5-5.7 mg L^{-1} (flooded).

The authors estimated gilvin leaching from litter using a "humic acid (HA) equivalent" concept, derived by drawing an analogy between the spectrophotometric properties of gilvin and those of humic acid[22]. The total amount of gilvin leached over the wet season was in the order: flooded gum > jarrah > blue gum > banksia, irrespective of 'flooded' and 'non-flooded' conditions. Leaf litter of flooded gum and jarrah can produce 8.5-14.7 (mg gilvin g^{-1} litter) via leaching over the wet season. Banksia leaves leached little gilvin under either flooded or non-flooded conditions, equivalent to 7% of that leached from the flooded gum. Thus the Eucalyptus species such as flooded gum and jarrah, common in wooded catchments in the region, appeared to be a major source of yellow coloured substances (gilvin) under annual rainfall conditions of south-western Australia.

Litter decomposition and nutrient mobility

In a parallel study the authors placed jarrah (*Eucalyptus marginata*) and banksia (*Banksia menziesii*) leaflitter at an upland (woodland) site and a wetland site along a hillslope transect, and litter weight and nutrient contents were monitored for two years to understand the rates of litter turnover and nutrient release. Decomposition of leaf litter was rapid at the commencement of the rain season but slowed rapidly in the following period, and 1/2 to 1/3 of litter weight remaining after two years. A two-substrate quality decay model was used to simulate the weight loss, which well described litter weight loss during the 2-year field decomposition (R^2 = 0.97-0.99). The half-lives were predicted to be 2.6-3.2 weeks (labile fraction) and 6.4-6.9 years (recalcitrant fraction) for *E. marginata*, and 1.0-1.7 weeks (labile) and 6.6-9.9 years (recalcitrant) for banksia. These predicted parameters for decomposition of the Jarrah leaves agreed with those reported in a recent study by OConnell and Mendham[23] on decomposition (2 mm mesh) of *E. marginata* leaf litter, in a location ca. 30 km east of our study site.

The loss of K, Mg and S was correlated with weight loss of litter (R^2 = 0.77-0.94, $p < 0.03$-0.001), and nutrient mobility was found to be K = Mg = S > Ca > P, regardless of site and species differences. The authors found a 129% increase of P mass in decomposed *E. marginata* litter and a 174% increase in banksia litter in the woodland site over a 275-day observation period, despite a significant weight loss during the period. Such data may suggest that the woodland litter can, at least temporarily, be an efficient system in retaining P, and the phenomenon was probably associated with microbial biomass development in response to the low P supply in the soils. Overall, the between-species difference (e.g. *E. marginata* vs *B. menziesii*) on decomposition was clear, while site influences on weight loss and nutrient

dynamics were more subtle, and depended critically on site microclimatic conditions.

Catchment litter production

Leaf litter accounted for Ca 67% of the total litter on the woodland catchment of Thomsons lake. The authors estimated Ca. 3048 kg ha^{-1} yr^{-1} leaf litter produced on the catchment based on monthly litterfall collected using litter trays. Assuming an average litter P content of 0.5 g kg^{-1} and 60% P leached over the wet season under field conditions (which is the mean litter content for four species and leaching rates under non-flooded conditions), a simple calculation will derive 250 kg P $year^{-1}$ leached from the 274 ha catchment of the lake. This amount would equal an increase of 250 g P L^{-1} in lake water (based on lake volume in late September, 250 ha of 0.4 m depth), if all 250 kg P were transferred to the lake.

This equals a load of 0.91 kg P ha^{-1} yr^{-1} (before export from the Catchment) in response to annual leaf litter production on this catchment[21]. Such a source was relatively small compared with fertiliser P use in agricultural soils of the region (3.1-9.8 kg P ha^{-1} yr^{-1}). However, if most of the leached P were exported eventually from the sandy catchment (in view of the low P retention capacity of the soils), it would be comparable to the potential export from diffuse agricultural sources (P loss 0.11-1.67 kg P ha^{-1} yr^{-1}) reported by Gillingham and Thorrold[24], and comparable with P exported from farmed catchments in the region (0.12-0.89 kg P ha^{-1} yr^{-1})[25]. The latter led to the significant eutrophication of a major estuary in southwestern Australia, the Peel-Harvey Estuary, during 1990s[26]. The significance of catchment litter as a P source will thus need to be accounted for not only in understanding wetland ecology, but also ecosystem restoration and management in the region.

Fate of leached P—interaction with soil

A difficult question has been related to the movement of leachate P following the onset of winter rains. The low-gradient sandy landscapes in the region have a relatively high infiltration. The critical issues relevant to P transport include the leaching and decomposition patterns of litter P, precipitation on the catchment (the main driving force of P movement), and interactions between leaching forces and factors modifying P leaching. Overall, the volumes and concentrations of P leached from surface litter can be modified during infiltration and travel through soil layers. Delineating such processes is viewed as critical for assessing the potential of P export from these wooded landscapes.

The field leaching data showed that the 'first flush' generated a mean P load of 114.7 mg m^{-2} on the wooded catchment, and P leaching was correlated with rain intensity[27]. When litter was applied to bare, sandy soil and then subjected to rain leaching, a portion of P released from litter and soil appeared to be retained through litter-soil interactions. Such interactions reduced leachate P by 25.2-29.5% and 28.6-38.6%, equivalent to a P retention of 75 mg P m^{-2} through surface application and 81 mg P m^{-2} via burial (5 cm into soil). The P retention can be attributed to increased microbial immobilisation, concurrent with an increased nutrient flux from litter. It appears that as much as 1/4 -1/3 of the P released during the current year from litter and soil would be retained in the top soil horizons under the wet season conditions.

Consequently, litter leaching in the presence of soil was found to cause a significant time-lag (about a month) in the appearance of peak gilvin load, and reduced total gilvin in leachate over the wet season.

A prior study of litter-soil interactions on this catchment showed that heterotrophic microbial biomass can capture most leached P during early rains, resulting in a three-fold increase in microbial biomass-P. About 4.8 - 43.9 mg P kg^{-1} in surface soils was retained by soil microbial biomass, leaving only about 5% of 'leachable P' in soils as compared with that held in microbial biomass[28].

P and organic C (gilvin) was also leached from the woodland soil under the litter layer, which appears to derive from residues accumulated from previous years of leaching, including those retained in and/or dried from leachate during the dry season. This may imply that retention of P and gilvin in the woodland soils is a short-term process. There is a limited capacity for P retention in these sandy soils, and the previously-retained P may be remobilised in the following rainy season, when transport is likely to continue in the direction of soil water movement and groundwater flow.

P leaching and microbial activity

A transect was established from a wetland site to an upland site in the wooded catchment of Thomsons

Lake, to examine P dynamics and microbial response to litter leaching over the rainy seasons[13, 28]. The transect passed through the lakebed, a sedge area and the riparian zone, ending in woodland on the eastern catchment of the lake. Seven sites (including one control site) were selected along the transect, which are characterised by distinctive vegetation types, plant litter, and general morphological features.

Soil chambers were deployed along the transect to measure heterotrophic microbial activity. This was measured in the field as CO_2 efflux (range 47-176 mg CO_2 m^{-2} h^{-1}), and in the laboratory as substrate-induced-respiration (SIR; range 11-133 g g^{-1} h^{-1})[23]. SIR was positively correlated with soil organic content, and was concentrated in surface soils. In contrast, in the exposed lakebed most microbial biomass was below the surface, in the 10-30 cm depth zone. There were significant changes in nutrient dynamics in response to soil microbial activity. Before rain, P extracted by anion-exchange-membrane (P_{AEM}) was well correlated with site litter and plant debris ($R^2 = 0.95$, $p < 0.001$), suggesting that P_{AEM} in soils was litter-sourced. This relationship was modified during the wet season: There was an overall increase in microbial biomass P (P_{MB}; from average 7.5 to 21.6 g g^{-1}), and a decrease in P_{EAM} / P_{MB} (microbial biomass P) ratio in surface soils. Along the transect, the assimilation index P_{EAM} / P_{MB} declined towards the wetland, where soils were more silty and organic, and CO_2 production was significantly higher. The results suggest that heterotrophic microbial activity has a significant role in regulating P flux from catchment litter during the wet season, which would be likely to affect the mobility of P sourced from litter form catchment into the wetland.

The present data suggest a multi-factor regulated pathway of microbial activity on the transect. That is, litter and soil organic turnover on the catchment provided a rich resource of available P for microbial community in catchment soils. The microbial activity is reflected in soil respiration, and co-regulated by soil attributes and microclimatic factors such as moisture and temperature. The increased soil water and a small decrease in soil temperature (average 2.5-3.2°C between May and June) with the onset of the wet season responded primarily by increased microbial uptake, and consequently increased P_{MB} in surface soils and thereby lower ratios of P_{AEM} / P_{MB} along the transect[28].

The microbial P (P_{MB}) measured in the present study was reasonably close to those reported by Grierson and Adams[29] for a jarrah forest in south-western Australia, in which microbial P varied from less than 10 in late summer to more than 50 μg^{-1} during the wet season. Overall, the onset of the wet season under the moderate temperatures of the region favours surface heterotrophic microbial activity and the transfer of bioavailable P into microbial biomass. It is still not clear how mobile are microbial biomass and P_{MB} in soils during following rains. The extremely low P_{AEM} in surface soils, however, means much of the soluble P has been temporarily immobilised as particulate P. The data suggested that microbial respiration and microbial biomass were particularly associated with soil litter, though questions remain concerning biomass mobility and the further turnover of microbial biomass.

Responses of soil microbial activity to soil temperature, moisture and litter leaching were examined along the same transect over the wet season. Heterotrophic respiration (CO_2 efflux) was higher in the dried lakebed and riparian areas than in upland soils, and higher during the day than at night. CO_2 efflux along the transect was positively correlated with soil moisture[30]. There were significant variations in CO_2 efflux with time of sampling, largely caused by the effect of temperature. The addition of litter leachate significantly increased CO_2 efflux especially in soils from upland sites, which had lower moisture and nutrient contents. There was a difference in response of microbial respiration between upland soils and wetland sediments to litter leachate and the wetter, warmer conditions. In general, litter leachate enhanced heterotrophic microbial respiration, and more significantly under warmer conditions (31 °C). The fungal to bacterial ratio was 2.9-3.2 for surface litter and 0.7-1.0 for soils, suggesting fungal dominance in heterotrophic respiration of surface litter, but increased bacterial dominance in soils, especially in exposed sediments in the lakebed.

Transport of litter P to wetland

There are two possibilities for transferring catchment litter, and for litter to act as source of P in wetland P cycling. Firstly, the transport may be effected via direct litterfall and/or transport via decomposing organic debris, which can be realised by wind force and surface runoff. Nutrients such as P may also be exported via solubilised or mineralised components, carried by water from the catchment, via either surface or subsurface flow.

The transport of litter P during winter rains can be more complicated due to 1) a general lack of surface runoff on these low-gradient sandy landscapes; 2) time-variable interactions between leaching and factors modifying P concentration in the leachate, such as intermittent wetting and drying, and microbial activity[28]. Overall, in the absence of surface runoff the P leached from surface litter may be modified during infiltration and transport through soil matrices. It is therefore difficult to directly relate the amount of P released on the catchment to what is received by the wetland because of the unknown portion recycled within the catchment itself. Meantime, as mentioned above, the previously-retained P in the soil matrix may be remobilised in the following rainy seasons, and the overall traveling routes of leachate will be continued in the direction of the wetland depression.

With respect to aquatic ecology, it is important to ascertain the amount of nutrients received by the aquatic volume. To avoid transport complications and any biotic and any abiotic transformations that take place before nutrients reach the receiving waters, the authors developed a simple, in-lake approach to quantify influences of the key processes controlling water column P concentrations in shallow lakes[31].

The method involves using a field experimental design employing various types of transparent plexiglass columns (chambers) pushed into sediments, followed by synchronized monitoring of P concentrations within and without (outside) the chambers. Various processes including 1) mixing and circulation; 2) atmospheric input including dry fall and wet precipitation, and wind transport from adjacent areas; 3) groundwater, including upward subsurface flow; 4) sediment release or sedimentation can be partitioned and quantified in terms of their contributions to water column P (as total P, $\mu g\ m^{-2}\ d^{-1}$), based on a simple deductive method[31].

The method was applied at nearshore and offshore sites in Thomsons Lake. Atmospheric and groundwater inputs were found to be the two main processes contributing to P loadings to the wetland (1233 and 1010 μg P $m^{-2}\ d^{-1}$), but their influence was restricted to near-shore sites. Such findings are consistent with the groundwater transport pattern in wetlands of the region, i.e. shallow groundwater (more carbon or nutrient enriched) being transported to near shore areas while deeper groundwater flows to middle of the wetland[32]. The estimated influence on total P by mixing-circulation, atmosphere and groundwater were 2.4-25 times higher near the lake margin as compared with an offshore site. The wooded catchment studied here is in a nature reserve with little human pollution, and so P reaching the lake may be regarded as from catchment litter turnover. As this source is large and diffuse, it could well be the 'major' source of P in unfertilised landscapes, such as the severely leached wetland catchment studied here.

References

1. McArthur WM. Reference soils of south-western Australia. Perth: Department of Agriculture, Western Australia. 1991.

2. Davis JA, Rosich RS, Bradley JS, Growns JA, Schmidt LG, Cheal F. Wetland classification on the basis of water quality and invertebrate community data. Wetlands of the Swan Coastal Plain, Volume 6. Perth: Water Authority of Western Australia. 1993.

3. Robertson AI, Bunn SE, Boon PI, Walker KF. Sources, sinks and transformations of organic carbon in Australian floodplain rivers. *Marine and Freshwater Research* 1999; **50** : 813-829.

4. Xiong SJ, Nilsson C. Dynamics of leaf litter accumulation and its effects on riparian vegetation - a review. *Botanical Review* 1997; **63** : 240-264.

5. Reddy KR, Kadlec RH, Flaig E, Gale PM. Phosphorus retention in streams and wetlands: A review. *Critical Reviews in Environmental Science and Technology* 1999; **29** : 83-146.

6. Brinson MM, Bradshaw HD, Holmes RN, Elkins JB. Jr. Litterfall, stemflow, and throughfall nutrient fluxes in an alluvial swamp forest. *Ecology* 1980; **61** : 827-835.

7. McClain ME, Richey JE. Regional-scale linkages of terrestrial and lotic ecosystems in the Amazon basin. A conceptual model for organic matter. *Archiv Für Hydrobiologie*, Supplement 1996; **113** : 111-125.

8. Raich JW, Schlesinger WH. The global carbon dioxide flux in soil respiration and its relationship to vegetation and climate. *Tellus* 1992; **44** : 81-99.

9. Watt KM, Golladay SW. Organic matter dynamics in seasonally inundated, forested wetlands of the Gulf Coastal Plain. *Wetlands* 1999; **19** : 139-148.

10. Herbohn JL, Congdon RA. Ecosystem dynamics at disturbed and undisturbed sites in north Queensland wet tropical rain forest -III- nutrient returns to the forest floor through Litterfall. *J Trop Ecol* 1998; **14** : 217-229.

11. O'Connell AM, Menage PMA. Litterfall and nutrient cycling in karri (*Eucalyptus diversicolor* F. Muell.) forest in relation to stand age. *Australian J Ecology* 1982; **7** : 49-62.

12. Qiu S, McComb AJ. Properties of sediment phosphorus in seven wetlands of the Swan Coastal Plain, South-western Australia. *Wetlands* 2000; **26** : 267-279.

13. Qiu S, McComb AJ, Bell RW, Davis JA. Phosphorus dynamics from a vegetated catchment to lakebed during seasonal refilling. *Wetlands* 2004; **24** : 828-836.

14. Reddy KR, Diaz OA, Scinto LJ, Agami M. Phosphorus dynamics in selected wetlands and streams of the Lake Okeechobee Basin. *Ecol Eng* 1995; **5** : 183-207.

15. Paludan C, Morris JT. Distribution and speciation of phosphorus along a salinity gradient in interdunal marsh sediments. *Biogeochemistry* 1999; **45** : 197-221.

16. Wrigley TJ, Chambers JM, McComb AJ. Nutrient and gilvin levels in waters of coastal-plain wetlands in an agricultural area of Western Australia. *Aust J Marine and Freshwater Res* 1988; **39** : 685-694.

17. Hongve D. Production of dissolved organic carbon in forested catchments. *J Hydrology* 1999; **224** : 91-99.

18. Wrigley TJ, Cowan M. Octanol partition coefficients for wetland humus. *Water Res* 1995; **29** : 11-15.

19. Qiu S, McComb AJ, Bell RW. Phosphorus leaching from litterfall in wetland catchments of the Swan Coastal Plain, Southwestern Australia. *Hydrobiologia* 2002; **472** : 95-105.

20. Donohue R, Davidson WA, Peters NE, Nelson S, Jakowyna B. Trends in total phosphorus and total nitrogen concentrations of tributaries to the Swan-Canning Estuary, 1987-1998. *Hydrological Processes* 2001; **15** : 2411-2434.

21. McComb AJ, Qiu S, Bell RW. Catchment litter: a phosphorus source mobilized during seasonal rainfall. *Nutrient Cycling in Agroecosystems* 2007; **77** : 179-186.

22. Qiu S, McComb AJ, Bell RW, Davis JA. Estimating production of yellow substance (gilvin) from catchment leaflitter during seasonal rains. *Marine and Freshwater Res* 2005; **56** : 843-849.

23. O'Connell AM, Mendham DS. Impact of N and P fertilizer application on nutrient cycling in jarrah (*Eucalyptus marginata*) forests of south western Australia. *Biology of Fertilized Soil* 2004; **40** : 136-143.

24. Gillingham AG, Thorrold BS. A review of New Zealand research measuring phosphorus in runoff from pasture. *J Env Quality* 2000; **29** : 88-96.

25. Birch PB. Phosphorus export from coastal plain drainage into the Peel-Harvey estuarine system of Western Australia. *Aust J Marine and Freshwater Res* 1982; **33** : 23-32.

26. McComb AJ, Lukatelich RJ. Nutirents and plant biomass in Australia estuaries, with particular reference to South-western Australia. In: de Deckker, Williams WD, editors. Limnology in Australia. Melbourne : CSIRO, 1986. pp. 433-455.

27. Qiu S, McComb AJ, Bell RW, Davis JA. Leaflitter application to a sandy soil modifies phosphorus leaching over the wet season of south-western Australia. *Hydrobiologia* 2005; **545** : 33-44.

28. Qiu S, McComb AJ, Bell RW, Davis JA. Nutrient response to soil and litter metabolic activity in a transect across a seasonal wetland. *Marine and Freshwater Res* 2003; **54** : 243-252.

29. Grierson PF, Adams MA. Plant species affect acid phosphatase, ergosterol and microbial P in a Jarrah (*Eucalyptus marginata* Donn ex Sm.) forest in south-western Australia. *Soil Biol and Bioch* 2000; **32** : 1817-1827.

30. Qiu S, McComb AJ, Bell RW, Davis JA. Response of soil microbial activity to temperature, moisture and litter leaching on a wetland catchment during seasonal refilling. *Wetland Ecol and Management* 2005; **13** : 43-54.

31. Qiu S, McComb AJ, Bell RW, Davis JA. Partition processes controlling water column phosphorus concentrations in a shallow wetland. *Freshwater Biol* 2004; 49 : 563-575.

32. Townley LR., Turner JV, Barr AD, Trefry MG, Wright KD, Gailitis V, Harris GJ, Johnston CD. Wetlands of the Swan Coastal Plain, Volume 3, Interaction between lakes, wetlands and aquifers. Perth: Water Authority of Western Australia. 1993.

Proc. Nat. Acad. Sci. India, Sect. B, Vol. 78, Spl. Issue, 2008

Biodiversity of wetlands in Kashmir Himalaya

ASHOK K. PANDIT

Centre of Research for Development and P.G. Department of Environmental Science, University of Kashmir, Srinagar-190006, India.

e-mail : profakpandit@yahoo.co.in

Abstract

The paper presents a broad based critical assessment of the state-of-art of biodiversity of wetlands and shallow lakes in Kashmir Himalaya under different environmental conditions. The hydrological factors represent the chief milieu of conditions governing the occurrence of various macrophytic species and their associations. In all 117 species of macrophytes, belonging to 69 genera and 42 families, have been recorded in the aquatic and marshland vegetation of Kashmir. Similarly, a multitudinal number of more than 300 algal species belonging to phytoplankton, periphyton and phytobenthic communities and spread over to various taxonomic groups (Cyanophyceae, Chlorophyceae, Bacillariophyceae, Euglenophyceae, Xanthophyceae, Chrysophyceae, Cryptophyceae, and Dinophyceae) have been registered from wetland biotopes, the extent of their occurrence and growth being determined by a number of ecological factors. The rich biodiversity of wetlands is also indicated by 150 species of zooplankton, 79 species of meiobenthos, 17 species of macrobenthos, 45 species of macrofauna composed of molluscs, annelids, arthropods, fishes and amphibians and 45 species of birds. However, the overall deterioration of wetlands, due to diverse and intense anthropogenic pressures leading not only to the eutrophication but also the shrinking of these economically and ecologically important ecosystems, has resulted in the loss of much of the biodiversity.

Key words : Kashmir Himalaya, wetlands, macrophytes, benthos, plankton, diversity indices.

सारांश

प्रस्तुत पुनर्विलोकन विभिन्न वातावरणीय स्थितियो में कश्मीर हिमालय के आर्द्र भूमि और छिछली झीलों की जैव विविधता का विशिष्ट एवं व्यापक विवेचनात्मक मूल्याकन प्रस्तुत करता है। विभिन्न वृहदपादप प्रजातियो तथा इनके आपसी सबंधो को नियत्रित करने में प्रमुख भूमिका जल जनित कारको की होती है। कुल मिलाकर कश्मीर की जलीय और दलदली वनस्पतियो मे वृहदपादप की 117 प्रजातियॉ अभिलेखित की गई है जो 42 कुलों के 69 जातियों की सदस्य है। इसी प्रकार आर्द 'भूमि, जैव वासक से 300 से अधिक संख्या मे अगणित पादप प्लवक, परिपादप और पादप निवलस्थ समुदायो की शैवलीय प्रजातियॉ, जो साइनोफाइसी, क्लोरोफाइसी, बैसीलेरियोफाइसी, यूग्लीनोफाइसी, जैन्थोफाइसी, क्राइसोफाइसी, क्रिप्टोफाइसी और डायनोफाइसी कुलों से संबद्ध है, अभिलेखित की गई है। इनकी उपस्थिति तथा वृद्धि अनेक पारिस्थितिकीय कारको द्वारा निर्धारित होती है। आर्द–भूमि की धनी जैवविविधता प्राणिप्लवक का 150, मियोबन्थास की 79, गुरूनितल जीवजात की 17, मोलस्का,एनीलिडा, आर्थोपोडा, मछलियाँ तथा एम्फीबिया जैसे गुरू प्राणिजात की 45 और पक्षियों की 45 प्रजातियों द्वारा प्रदर्शित होती है। विभिन्न मानवजनित प्रबल दबावो से आर्द–भूमि के पूर्ण ह्रास के कारण इन आर्थिक तथा परिस्थितकीय रूपसे महत्वपूर्ण परितत्रो में न केवल यूट्रफिकेशन हुआ है अपितु इनका संकुचन भी हुआ है, जिसके परिणाम स्वरूप जैव–विविधता का अत्यधिक ह्रास हुआ है।

सांकेतिक शब्द : कश्मीर हिमालय, आर्द भूमि, वृहदपादप, बेन्थास, प्लवक, विविधता सूचकाक।

Introduction

The high altitude valley of Kashmir is a lacustrine basin of the intermontane depression existing between the Lesser and the Greater Himalaya. The picturesque valley abounds in a vast array of diversified types of freshwater wetlands (shallow lakes, marshes etc.) spread along the floodplains of River Jhelum. Wetlands, the complex hydrological and biogeochemical systems transitional between purely terrestrial and aquatic ones, are considered the earth's most productive ecosystems[1, 2, 3]. Evidently the wetland ecology is dynamic and remains ever-changing for its dwindling water depth, providing fluctuating transitional zones for vegetation to develop[4]. The numerous but varied freshwater ecosystems are of great aesthetic, cultural, socio- economic and ecological value, besides playing an important role in the conservation of water and genetic resources of both plants and animals. Despite their great values the wetlands have received little attention of ecologists and conservationists as they were often treated as wastelands and thus reclaimed for agriculture and housing purposes. It is only during the last thirty years the ecological and socio - eco-

nomic importance of these ecosystems has been recognized and some of the workers have concentrated their studies upon the most valuable pools of biodiversity, the wetlands, covering very large areas of Kashmir[5-24]. It is in this backdrop the present review is an attempt to collate all the available information regarding the status of biodiversity of wetlands in Kashmir Himalaya. For the sake of convenience, the present paper is divided into floral diversity and faunal diversity.

Floral Diversity

Algae

The algae can be classified, on the basis of their ecological distribution, into phytoplankton, periphyton and phytobenthos (epipelic algae) and comprise a multitudinous number of about 300 algal species belonging to Cyanophyceae, Chlorophyceae, Bacillariophyceae, Euglenophyceae, Xanthophyceae, Chrysophyceae, Cryptophyceae and Dinophyceae (Table 1). The extent of occurrence and growth of these microscopic plants is, however, determined by a number of environmental factors, the physico-chemical characteristics of water being the chief milleu of conditions governing their distribution and production. Although a number of studies have been carried out on the qualitative and quantitative aspects of phytoplankton, yet there is no comparability of the data presented by various investigators. There is enough evidence in literature to show that the difference in the dominant phytoplankton assemblages of the wetlands reflect difference in their trophic levels. Dal lake waters, in general, are low in available phosphorus which possibly is a limiting factor for phytoplankton blooms in the lake[25]. Overall 117 species of phytoplankton belonging to 71 genera have been identified by Trisal[26], the dominance pattern being Chlorophyceae followed by Bacillariophyceae, Cyanophyceae and Euglenophyceae. In contrast to the findings of Trisal[26], Kant and Kachroo[27] reported a much greater number of phytoplankton species encompassing 150 species of Chlorophyceae and 86 species of Bacillariophyceae which point out to the fact that the number of phytoplankton species is exceptionally great in this shallow biotope. The latter studies, are further corroborated by the findings of Pandit and Pandit[28] who reported the periphytic flora of Dal lake to be composed of 264 species and subspecies spread over 84 genera on *Potamogeton lucens* and 239 taxa belonging to 77 genera on *Myriophyllum spicatum*, with the pattern of dominance among various algal groups being Chlorophyceae> Bacillariophyceae > Cyanophyceae > Euglenophyceae> Dinophyceae > Chrysophyceae > Xanthophyceae. However, on the basis of biomass, the pattern of dominance among various periphytic algae is: Bacillariophyceae > Chlorophyceae > Cyanophyceae > Euglenophyceae > other groups. In a more recent study Bhat and Pandit[29] reported 143 species of phytoplankton comprised of Cyanophyceae (31), Chlorophyceae (49), Bacillariophyceae (40), Euglenophyceae (14), Chrysophyceae (3), Dinophyceae (3) and Xanthophyceae (3) from a very shallow lake, Anchar, giving a look of a typical wetland.

A total of 190 species of phytoplankton have been reported in five typical wetlands (Nowgam, Malgam, Haigam, Mirgund and Hokersar) of Kashmir of which 20 belong to Cyanophyceae, 72 to Chlorophyceae, 60 to Bacillariophyceae, 3 each to Xanthophyceae, Chrysophyceae and Dinophyceae[14, 15, 30]. The maximum number of species is, however, recorded in Nowgam (189), followed by Haigam (183), Mirgund (179), Malgam (177) and decreasing to minimum in Hokersar (156). The phytoplankton community reaches its maximum development in spring and autumn when the number of constituent species in wetlands is also the highest[31]. Although the mean number of species in wetlands, is high, yet only a comparatively small number of species contribute appreciably to the total density and biomass, presumably owing to the state of dynamic balance of plankton community; the species competing for the same materials in fairly uniform environment. In such a process some species profit more than others and hence dominate the scene[15, 31]. In a later study on phytoplankton dynamics in Hokersar wetland during 2000-01 (Table 1) only 138 species of phytoplankton were identified with a clear dominance of Chlorophyceae (50), over Bacillariophyceae (43), Cyanophyceae (24), Euglenophyceae (15), Xanthophyceae (3), Chrysophyceae (2) and Dinophyceae (01)[21, 32]. However, Kaul *et al.*[25] obtained a higher number of phytoplankton species in wetlands as compared to that in the sewage ponds and lakes in that order, the rich assemblages in wetlands being attributed to macrophytic cover, floods and availability of nutrients favouring many heterogenous niches, both spatial and temporal. The filamentous green algae are favoured by higher transparency and temperature condition. Although no systematic survey of epipelic

algae growing in the lake sediments has been carried out, yet it has been conducted for the wetlands[9]. The author registered a total of 155 species of sediment algae spreading over the various taxonomic groups with the following breakup: Cyanophyceae-18, Chlorophyceae-37, Bacillariophyceae-61, Xanthophyceae-1, Chrysophyceae-2, Dinophyceae-5, Cryptophyceae-4 and Euglenophyceae-27. Due to only little depth and close proximity of bottom to the surface water in wetlands, a large number of phytoplankton species are regularly present in the bottom flora as well[9, 14].

An overview of the algal component of Kashmir wetlands indicates the lesser species diversity of the microscopic plants when compared with the total algal flora, comprised of 406 species distributed over 108 genera inhabiting rivers, streams, ponds, pools and lakes from Kashmir[33, 34].

Table 1 - List of phytoplankton species recorded from Kashmir wetlands including Hokersar (Ramsar Site) during 1980 and Hokersar alone during 2001[9, 21].

S. No.		Kashmir wetlands (1980)*	Hokersar (2001)**
CYANOPHYCEAE			
1.	*Anabaena affinis*	P	P
2.	*A. spiroides*	P	P
3.	*A. solitaria*	P	P
4.	*Aphanizomenon holsaticum*	-	P
5.	*Chrococcus turgidus*	P	P
6.	*Coccobloris stagnina*	-	P
7.	*Cylindrospemum lichniforme*	P	P
8.	*Gloeotrichia echinulata*	P	P
9.	*Gomphosphaeria wichurae*	P	P
10.	*Lyngbya aestuarii*	P	P
11.	*Merismopedia punctata*	P	P
12.	*Microcystis aeruginosa*	P	P
13.	*M flos aquae*	P	P
14.	*Nodularia spumigena*	P	P
15.	*Nostoc* sp.	P	-
16.	*N. linkia*	-	P
17.	*Oscillatoria agardhii*	P	-
18.	*O.annae*	-	P
19.	*O.foreani*	-	P
20.	*O limnetica*	P	P
21.	*O.limosa*	P	P
22.	*O.tenuis*	-	P
23.	*Radiocystis geminata*	P	P
24.	*Rivularia minutula*	P	P
25.	*Spirulina major*	P	-
26.	*Synechococcus ambiguus*	P	-
27.	*Westiella* sp.	-	P
	CHLOROPHYCEAE		
(i)	**Volvocales**		
28.	*Chlamydomonas* sp.	P	P
29.	*Endorina elegans*	P	P
30.	*Gonium pectorale*	P	P
31.	*Hydrodictyon* sp.	-	P
32.	*Pandorina morum*	P	P
33.	*Volvox globater*	P	-
34.	*V. monance*	P	P
(ii)	**Chlorococcales**		
35.	*Akistrodesmus fusiformis*	P	P
36.	*A. spiralis*	P	P
37.	*A. falcatus*	P	-
38.	*Chlorella vulgaris*	P	P
39.	*Chlorococcum humicola*	P	P
40.	*Coelastrum* sp.	P	P
41.	*Crucigenia lauterbornei*	P	P
42.	*Excentroshpaera viridus*	P	-
43.	*Nephrocytium agardhianum*	P	-
44.	*Oocystis solitaria*	P	-
45.	*Pediastrum biradatum*	P	-

S. No.		Kashmir wetlands (1980)*	Hokersar (2001)**
46.	*P. boryanum*	P	P
47.	*P. duplex*	P	P
48.	*P. tetras*	-	P
49.	*Radiococcus nimbatus*	P	P
50.	*Scenedesmus baculiformıs*	P	P
51.	*S.ecornis*	P	P
52.	*S.quadricauda*	P	P
53.	*Sphaerocystis schroeteri*	P	P
54.	*Tetrastrum staurogeniaeniaeforme*	P	-
55.	*Tetraedron bifidium*	P	P
56.	*T.mutıcum*	P	P
57.	*T.triginum*	P	-
(iii)	**Ulotrichales**		
58.	*Binuclearia tetrana*	P	P
59.	*Hormidium subtile*	-	P
60.	*Microspora amoena*	P	P
61.	*Rhizoclonıum hieroglyphium*	-	P
62.	*Ulothrix zonata*	P	-
63.	*Uronema elongatum*	P	P
(iv)	**Chaetrophorales**		
64.	*Coleochaete scutata*	P	P
65.	*Chaetophora incrassata*	P	P
66.	*Chaetonema irregulare*	P	-
67.	*Dermatophyton radians*	P	P
(v)	**Ulvales**		
68.	*Draparnaldia* sp.	-	P
69.	*Enteromorpha intestina*	-	P
(vi)	**Oedogoniales**		
70.	*Oedognium crenonulatocostatum*	P	-
71.	*O. inscuspicuum*	P	-
72.	*Oedocladium operculatum*	-	P
73.	*Oedogonium* sp.	-	P

S. No.		Kashmir wetlands (1980)*	Hokersar (2001)**
(vi)	**Cladophorales**		
74.	*Cladophora glomerata*	P	P
75.	*Pithophora oedogonıa*	-	P
(vii)	**Congugales**		
76.	*Anthrodesmus convergens*	P	-
77.	*A. arcuats*	P	-
78.	*Clostrium ehrenbergii*	P	P
79.	*C. dinae*	P	-
80.	*C. leibleinii*	P	-
81.	*C. monliferum*	P	-
82.	*Cosmarium contractum*	P	-
83.	*C. depressum*	P	-
84.	*C. granatum*	P	P
85.	*C.moniliforme*	P	-
86.	*C. monomazum*	P	-
87.	*C.obtusatum*	P	-
88.	*C. pachyderum*	P	-
90.	*C.pseudonitidulum*	P	-
91.	*C.setaceum*	-	P
92.	*C. subcostatum*	P	-
93.	*C. venustum*	P	-
94.	*Desmidium aptogonium*	P	-
95.	*D. bayleyi*	P	-
96.	*Euastrum germitum*	P	-
97.	*Micrasterias crux-melipensis*	P	-
98.	*M. papillifera*	P	-
99.	*Pleurotaenium ehernbergii*	P	-
100.	*P. trabecula*	P	-
101.	*Staurastrium dejectum*	P	-
102.	*S.paradoxum*	P	-
103.	*S.sebaldi*	P	-
104.	*S. tetracerum*	P	-

S. No.		Kashmir wetlands (1980)*	Hokersar (2001)**
105.	*Staurodesumus subulatus*	P	-
106.	*S. vıladus*	P	-
107.	*Mougetia transeaui*	P	P
108.	*Spirogyra* sp.	P	P
109.	*Zygnema cylindrosporum*	P	P
	BACILLARIOPHYCEAE		
110.	*Amphora ovalıs*	P	P
111.	*Anomoneis sphaerophora*	P	P
112.	*Astronella formosa*	P	P
113.	*Bacillaria paradoxa*	P	P
114.	*Brachysira vitrea*	-	P
115.	*Calonies* sp.	P	-
116.	*Ceratonies arcus*	P	P
117.	*Coconeis placentula*	P	P
118.	*Cyclotella stelligera*	P	P
119.	*Cymatopleura solea*	P	-
120.	*Cymbella cistula*	P	P
121.	*Cymbella cymbiformis*	P	P
123.	*C.muelleri*	P	-
124.	*C.parva*	P	-
125.	*C. turgida*	P	-
126.	*C.ventricosa*	P	P
127.	*Gyrosigma kutzingii*	-	P
128.	*Diatomella balfouriana*	P	-
129.	*D. elongatia*	P	P
130.	*Epithemia turgida*	P	P
131.	*Eunotia praerupta*	P	-
132.	*E.naeigili*	-	P
133.	*Fragillaria capunica*	P	P
134.	*F.construens*	P	-
135.	*F. vaucherii*	P	-
136.	*Gomphonema constrictum*	P	-
137.	*G.germinatum*	P	-
138.	*G.gracile*	P	P
139.	*G.longıceps*	P	.-
140.	*G.minuta*	-	P
141.	*G.parvulum*	P	-
142.	*G subventricosum*	P	-
143.	*Hantzschia amphioxys*	P	-
144.	*Melosira granulata*	P	P
145.	*Meridion sp.*	P	P
146.	*M.circulara*	-	P
147.	*Navicula brasiliana*	P	-
148.	*N.cari*	P	P
149.	*N.cincta*	P	P
150.	*N.curta*	P	-
151.	*N.cuspidata*	P	P
152.	*N.confervacea*	P	-
153.	*N.exigua*	P	-
154.	*N.grimmei*	P	-
155.	*N.halophila*	P	-
156.	*N.kanemi*	P	-
157.	*N.mollissima*	P	-
158.	*N.pseudomuralis*	P	-
159.	*N. radiosa*	P	
160.	*N.ruttneri*	P	-
161.	*N.seminuloides*	P	-
162.	*N.subtillisma*	-	P
163.	*Nitzschia sigmoidea*	P	-
164.	*N.chaurli*	-	P
165.	*N.diversa*		-
166.	*N.radicula*		
167.	*Pinnularia cardinalis*	P	-
168.	*P. interrupta*	P	-

S. No.		Kashmir wetlands (1980)*	Hokersar (2001)**
169.	*P. nobilis*		-
170.	*P.sudetica*	-	P
171.	*Placaneis pseudangilica*	-	P
172.	*Rhopalodia gibba*	P	-
173.	*Stanroneis phoenicenteron*	P	-
174.	*Surirella capronii*	-	P
175.	*S.ovata*	P	
176.	*S.robusta*	P	P
177.	*Synedra acus*	P	P
178.	*S.berolinsensis*	-	P
179.	*S. capitata*	P	P
180.	*S. ulna*	P	P
181.	*Tabellaria flocculosa*	P	P
EUGLENOPHYCEAE			
182.	*Astatia klebsii*	-	P
183.	*Astatia* sp.	P	-
184.	*Chlorogonium sp.*	-	P
185.	*Euglena acus*	P	P
186.	*E. deses*	P	P
187.	*E.limnophila*	P	-
188.	*E.oxyuris*	P	P
189.	*E polymorpha*	P	-
190.	*E.spirogyra*	P	-
191.	*E.viridis*	P	P
192.	*Euglenaria* sp.	-	P
193.	*Euglenopsis vorax*	-	P
194.	*Euttrepia viridis*	P	P
195.	*Gonyaulax* sp.	-	P
196.	*Gymnastica elegens*	P	-
197.	*Lepocynclis acicularis*	P	-
198.	*L.ovum*	P	P
199.	*L.texta*	P	P

S. No.		Kashmir wetlands (1980)*	Hokersar (2001)**
200.	*Phacus acuminatus*	P	P
201.	*P.caudatus-minor*	P	P
202.	*P.curvicauda*	P	-
203.	*P.longicauda*	P	-
204.	*P.orbicularis*	P	P
205.	*P.platalae*	P	-
206.	*P pleuronectes*	P	-
207.	*P.pyrum*	P	-
208.	*P.suecious*	P	-
209.	*Trachelomonas abrupta*	P	-
210.	*T.hispida*	P	-
211.	*T.intermedie*	P	-
212.	*T.plantonica*	P	-
213.	*T superba*	P	-
214.	*T.volvocina*	P	-
215.	*Stromomonas maxima*	P	-
DINOPHYCEAE			
216.	*Ceratium hirundinella*	P	-
217.	*Gymnodinium aeruginosum*	P	-
218.	*Perdinium* sp.	P	P
CHRYSOPHYCEAE			
219.	*Chrysamoeba radians*	P	-
220.	*Dinobryon borgei*	-	P
221.	*D. sertularia*	P	-
222.	*D.sociale*	P	-
223.	*Tribonema bombyeinum*	-	P
XANTHOPHYCEAE			
224.	*Botrydiopsis arhiza*	P	P
225.	*Ophiocytium capitatum*	P	P
226.	*Vaucheria* sp.	P	P

Source: * Pandit[9] ** Rather[21]

Macrophytes

Wetlands have been called the biological supermarkets for the excessive food chains and rich biodiversity they support[20]. As wetlands represent the last stage of lake succession, there is great infestation of macrophytes particularly emergents which act as nutrient pumps. It has been emphasized that the aquatic plants occupy great diversity of niches and display morphological plasticity. At the same time they also occur in considerably wide range of form and size though not as great as seen among the terrestrial plants. Structure and species composition of the wetland plants is purely governed by ecological stresses including floods, erosion and deposition. Flooding and water level decrease cause impending of natural drainage and draining - filling respectively. In diverse habitats, species composition is also controlled by environmental factors and the area under occupation. Thus, the amplitude of water level fluctuations is the main controlling factor. Further many authors believe that the hydrological factors represent the chief milieu of conditions governing the occurrence and growth of various macrophytic species and their associations. Water depth and its associated influences are opined to influence the occurrence and extent of individual plant species, while soil type and nutrient composition have little importance in controlling macrophytic distribution. However, for submerged plants the turbidity of water is an additional factor in determining the extent of their colonization[8, 9, 11, 14, 16, 35, 36, 37].

In shallow wetlands, unlike lakes, no typical macrophytic zonation is distinguishable; instead several plant species occur together which result in a complex physiognomy. On structural basis, particularly height and position of macrophytes within the wetland, the herbaceous wetlands are dominated by emergents, rooted floating-leaf types and submerged depending upon water depth and associated factors. The emergent macrophytes have further been classified into three strata : (i) tall emergents with shoots more than one meter, (ii) low emergents with shoots between 25 and 100 cm and (iii) ground layer species with shoots less than 25 cm. The studies on phytosociology and community architecture in some typical wetlands of Kashmir have been carried out in details[6, 8]. Thus, while Handoo and Kaul[6] reported about 42, 32, 19 and 18 species in Malangpora, Kranchu, Shalabogh and Hokersar wetlands, Pandit[14] reported 29, 24, 20, 21, and 37 taxa of macrophytes in Haigam, Hokersar, Mirgund, Nowgam and Malgam wetlands respectively (Table 2). Regarding species number and composition, many workers have reported varied number of macrophyte species from the wetlands at different times. For instance, while Kaul and Zutshi[38] reported 67 species from Hokersar wetland, Pandit[9] in his extensive study reported only 24 species of macrophytes from this closed type wetland. Handoo and Kaul[6] held water fluctuations responsible for the species decline and further reported only18 macrophytic species from the said wetland. In contrast, Kak[18] in his taxonomic survey reported 58 species out of which 44 were rare to the wetland. In the later studies, Khan[19] while studying the biodiversity of Hokersar wetland reported a total of 25 macrophytic species, encompassing 14 emergents. Gangoo and Makaya[20] registered 24 species from the same, the latter holding anthropogenic pressures to be responsible for vagetational changes (Table 2).

Table 2 - Number of macrophytic species recorded over a period of 40 years by different workers from Hokersar wetlands[23].

S. No.	Name of the author	Year	Number of macrophytes
1.	Kaul and Zuthshi	1963(cf. 1967)	85
2.	Kaul and Zuthshi	1967	67
3.	Pandit	1980	24
4.	Handoo	1982	19
5.	Handoo and Kaul	1982	18
6.	Kak	1990	58
7.	Pandit	1991	24
8.	Khan	2000	25
9.	Gangoo and Makaya	2000	24
10.	Ravinder Kumar	2005	46

A perusal of data in Table 2 depicts significant temporal variations in the species composition. Thus, according to earlier reports[38] Hokersar sustained 85 species of macrophytes in 1963 and thereafter a decreasing trend was registered. Pandit[9] held that decrease in the number of species in Hokersar wetland from 85 in 1963 to 24 in 1980 due to increasing frequency of floods and increasing population causing greater anthropogenic pressures on the wetland biotope. Pandit and Qadri[17] further studied the impact of floods on the vegetation pattern of Hokersar and held silt deposition responsible for luxuriant growth of *Sparganium ramosum*

replacing *Phragmites australis*. Pandit[13], while discussing conservational strategies of wetlands, again held floods and siltation responsible for the disappearance of species like *Nelumbium nucifera, Euryale ferox* and *Acorus calamus* reported earlier by Lawrence[34] and Kaul and Zutshi[38]. Contrary to the inventory of Pandit and Ravinder Kumar[23], Khan[19] did not enlist the species like *Ceratophyllum demersum, Myriophyllum spicatum, Utricularia* sp., *Nymphaea alba, Sium latijugum, Menyanthese trifoliate, Hippuris vulgaris, Bidens cernua, Hydrocharis dubia* etc. which have been recorded abundantly during the recent investigation except *Menynanthese trifoliata* which was found to be a rare species. As regards the number of emergents, the studies of Kak[18] and Kaul and Zutshi[38] show close proximity with the present study. However, for other types of macrophytes, all the previous reports coincide with the studies of Pandit and Ravinder Kumar[23]. The increase in species number from 24 (Pandit[9]) to the present 46, with 30 emergents, 7 rooted floating- leaf type, 2 free floating and 7 submergeds[9, 40, 41], can be attributed to the possible reason of

Table 3 - Species composition of macrophytes in Queen wetland of Kashmir Hokersar, during 2002[89].

S.No.	Plant taxa
	Emergents
1.	*Alisma plantago -aquatica* Linn.
2.	*Batrachium trycophyllum* v.d. Borsche
3.	*Bidens cernua* Linn.
4.	*Carex* sp.
5.	*Cyperus defformis* Linn.
6.	*Echinocloa crusgalli* Beauv.
7.	*Eleocharis palustris* Linn.
8.	*Epilobium hirsutum* Linn.
9.	*Fimbrystylis dictoma* Poem & Schutt.
10.	*Galium palustrie* Linn.
11.	*Hippuris vulgaris* Linn.
12.	*Lycopus europus* Linn.
13.	*Mentha arvensis* Linn.
14.	*Mentha sylvestris* Linn.
15.	*Menyanthese trifoliata* Linn.
16.	*Monochoria vaginalis* (Brum.f) Presl.
17.	*Myosotis sylvatica* Hoff.
18.	*Myriophyllum verticillatum* Linn
19.	*Nasturtium officinale* R.Br.
20.	*Paspalum paspaloides* (Michx) Scribner
21.	*Phragmites australis* Trin.
22.	*Polygonum amphibium* Linn.
23.	*Polygonum hydropiper* Linn.
24.	*Ranunculus scleratus* Linn.
25.	*Ranunculus lingua* Linn.
26.	*Sagittaria sagittifolia* Linn.
27.	*Scirpus triqueter* Linn.
28.	*Sium latijugum* C.B.C.L.
29.	*Sparganium ramosum* Huds.
30.	*Typha angustata* Bory & Chaub.
Rooted floating - leaf type	
31.	*Hydrocharis dubia* (Blume) Bacquer
32.	*Marsilea quadrifolia* Linn.
33.	*Nymphaea alba* Linn.
34.	*Nymphaea pygmea* Linn.
35.	*Nymphoides peltatum* (Gmel) Kuntze
36.	*Potamogeton natans* Linn.
37.	*Trapa natans* Linn.
Free floating type	
38.	*Lemna* sp.
39.	*Salvinia natans* Linn.
Submergeds	
40.	*Ceratophyllum demersum* Linn.
41.	*Hydrilla verticillata* (L.F.) Royle.
42.	*Myriophyllum spicatum* Linn.
43.	*Potamogeton crispus* Linn.
44.	*Potamogeton lucens* Linn.
45.	*Potamogeton pucillus* Roxb.
46.	*Utricularia aurea* Lour.

Table 4 - List of macrophytic species recorded from Wular lake during March 2002 to February 2004[42].

S.No.	Name of the Species	Family
Emergents		
1.	*Alisma plantago -aquatica* Linn.	Alismataceae
2.	*Carex* sp.	Cyperaceae
3.	*Myriophyllum verticillatum* Linn	Haloragaceae
4.	*Nasturtium officinale* R.B.r.	Brassicaceae
5.	*Phragmites australis* Trin.	Poaceae
6.	*Polygonum amphibium* Linn.	Polygonaceae
7.	*Sagittaria sagittifolia* Linn.	Alismataceae
8.	*Sparganium ramosum* Huds.	Sparganiaceae
9.	*Typha angustata* Bory & Chaub.	Typhaceae
Rooted floating - leaf type		
10.	*Hydrocharis dubia* (Blume) Bacquer	Hydrocharitaceae
11.	*Nelumbo nucifera* Gaertn	Nelumbonaceae
12.	*Nymphaea alba* Linn.	Nymphaeceae
13.	*Nymphoides peltatum* (Gmel) Kuntze	Menyanthaceae
14.	*Potamogeton natans* Linn.	Poatmogetonaceae
15.	*Trapa natans* Linn.	Trapaceae
Free floating type		
16.	*Azolla pinnata*	Salviniacea
17.	*Lemna gibba*	Lemnaceae
18.	*Lemna minor*	Lemnaceae
19.	*Salvinia natans* Linn.	Salviniaceae
Submergeds		
20.	*Ceratophyllum demersum* Linn.	Ceratophyllaceae
21.	*Hydrilla verticillata* (L.F.) Royle.	Hydrocharitaceae
22.	*Myriophyllum spicatum* Linn.	Haloragaceae
23.	*Potamogeton crispus* Linn.	Potmogetonaceae
24.	*Potamogeton lucens* Linn.	Potmogetonaceae
25.	*Potamogeton pucillus* Roxb.	Potmogetonaceae

improvement in flood situation following dry weather conditions leading mostly to summer draw- down during the recent years and restricted human interference (Table 3). In a more recent study on Wular, the largest freshwater lake in the Indian subcontinent being recognized as a Wetland of International Importance, 25 macrophytic species belonging to 17 families were recognized[42]. The maximum number of species at the Ramsar site was recorded for Potamogetonnacea (4), followed by Alismataceae, Haloragaceae, Hydrocharitaceae and Lemnaceae with 2 species each. The rest of the families were monotypic. Despite the fact that Potamogetonnacea representing the maximum number of species (non- emergent), the emer-

gent class is dominating the vegetation in the wetland (Table 4). In another study on the distribution of aquatic vegetation of Ahansar, a shallow rural lake, Rather *et al.*[43] registered a total of 28 species of macrophytes of which the maximum number was recorded for emergents (13), followed by submergeds (7), rooted floating-leaf type (6) and free floating type (2). *Phragmites australis, Myriophyllum verticillatum* and *Typha angustata* were the dominant species in emergents. The values for Shanon-Weiner species diversity index for Ahansar ranged between 2.66 and 2.96[44].

Handoo and Kaul[6] further noticed a gradual increase in species richness from 1.2 to 4.76 with a decrease in water depth. At Malangpora, the low growing emergents like *Scirpus palustris, Eleocharis palustris* and *Cyperus serotinus* and ground layer species like *Polygonum hydropiper, Myosotis sylvatica, Galium hertifolium* and *Marsilea quadrifolia* were common. They together represented 73.3-86.8% of the density at the study site[6].

In contrast, tall growing emergents like *Phragmites australis, Scirpus lacustris* and *Typha andustata* had high relative frequencies at both Shalabogh and Kranchu wetlands. The tall growing emergents mainly *T.angustata, P.australis, Phalaris arundinaceae* and *Sparganium ramosum*, accounted for 61.5 - 64.6% and 28.8- 49.3% of the total density at these two sites respectively. However, at Kranchu the floating-leaf species (*Nymphoides peltatum* and *Potamogeton natans*) and submerged species (*Myriophyllum spicatum* and *Ranunculus aquatilis*) were almost fairly present. In Haigam, the dominant vegetation comprises low growing emergents like *Scirpus palutris, Carex* sp., and *Eleochatis palutris* and the tall growing emergents like *P. australis, S. lacustris, T. angustata* and *Sparganium erectum* take the position of co-dominant, occurring in somewhat pure or isolated stands[45]. However, in Nowgam *P. australis, S. erectum, Scripus lacustris, Acorus calamus* and *Trapa natans* are common. Malgam has a typical prairie look. By interwining rhizomatous parts of macrophytes, large extensive floating islands are being formed in this wetland. The common macrophytic species comprise *P.australis* (dwarf ecotype), *S.lacustris, Nymphaea candida, Nymphoides peltatum* and *Chara zeylanica*. In deeper wetlands like Hokersar and Mirgund the increased water depth results in the greater establishment of floating- leaf

Table 5 - Total number of species and annual primary production* of different wetlands of Kashmir[14].

S. No.	Wetland site	Number of species**	Annual increment of macrophytes (gm^{-1})	Community architecture***
1.	Nowgam	21	845	Dominated by tall growing emergents
2.	Malangpora	42	1790	Dominated by sedge- meadow species
3	Tullamulla	35	1840	Dominated by sedge - meadow species
4	Mirgund	20	730	Mainly dominated by tall growing emergents
5.	Shalabogh	19	3073	Mainly dominated by tall growing emergents
6.	Kranchu	32	846	Mainly dominated by tall growing emergents
7.	Malgam	37	312	Mainly dominated by tall growing emergents
8.	Haigam	29	1886	Dominated by low growing emergents and tall growing emergents take the position of co-dominants
9.	Narkora	18	699	Dominated mainly by rooted floating- leaf types
10.	Hokersar ✧	18	502	Dominated mainly by rooted floating- leaf types

* In all the wetlands sites macrophytes are the main contributors of carbon fixation.

** The species diversity is high in shallow and low in deeper sites.

*** In the shallower wetlands species of tall growing emergent, low growing emergents and ground layer species, all grow together resulting in the economy of space and light within the multitier architecture of the vegetation

✧ Ramsar Site, A wetland of International Importance

species. While in Mirgund floating-leaf types like *Nymphaea alba, Potamogeton natans, Hydrocharis dubia* and *Trapa natans* are the dominant forms, in Hokersar *Trapa natans* and *Trapa bispinosa* together had 55.2% to 91.7% relative frequency. *Phragmites australis* (tall ecotype) and *Nymphaea alba* are also the other main colonizers at the latter site. In general, floating-leaf species contributed more at Hokersar than in other wetlands. *Trapa natans* still claims a good coverage in Wular lake, a Wetland of International Importance (Ramsar Site).In Wular, the growth of submerged vegetation is greatly restricted due to the heavy turbidity brought about by the suspended silt, as is true for other wetlands also. S. Kaul[8] while drawing a comparison of some typical wetlands of Kashmir, on the basis of their community architecture reveals shallower wetlands (Malgam, Nowgam and Haigam) having a water depth of < 0.80 cm to be conductive for the establishment of an association of emergents like *Phragmites australis, Typha angustata, Scrispus lacustris, Sparganium erectum* and *Myriophyllum verticillatum* whereas the deeper wetlands (Mirgund and Hokersar) are colonized by *Trapa- Nymphoides* association. The author further opined the deeper wetlands, predominantly covered by floating- leaf types, to be structurally less complex compared to other shallow wetlands.

The vegetation of wetlands is specially adapted to survive in different conditions and the Kashmir wetlands host a number of species found no where else in the country. The most striking feature of the wetlands is the large amount of photosynthesis within the system especially by macrophytes. Their growth increases from minimum in February- April to maximum in August-September. Among the various life - forms, the reed swamps show the maximum biomass; the standing crop values for *Phragmites australis, Typha angustata, T. latifolia, Scirpus lacustris* and *Sparganium erectum* being between 1,016 to 3,216, 866 to 5,400, 920 to 2,288, 884 to 1,280 and 625 to 1, 838 gm^{-2} respectively. Among the rooted floating-leaf types *Nelumbium nucifera* (found in Dal, Anchar and Manasbal lakes) and *Trapa natans* (found in Hokarsar and Wular) accumulates relatively higher biomass. The biomass values of submergeds and free- floating types are quite low as compared to emergents and floating-leaf types. In general, some of the most productive wetlands sustained a macrophytic biomass ranging between 58-584 t ha^{-1}.These values are definitely higher than those of the lakes.

Dwindling Plant Resources

The wetlands in Kashmir have remained almost neglected because of the traditional altitude of the people, who still consider wetlands as "wastelands" serving dumping grounds for waste and "sinks" during floods bringing in huge quantities of allochthonous material like silt and domestic refuse. Increased human pressures, coupled with recurring floods, have brought about a series of changes in the biotic set up of water bodies. For instance, before the floods of 1952 and 1959, Hokersar wetland, being a Ramsar site and one of the most important duck shooting sites in the past in Kashmir, was rich sources of some economically important plants like *Trapa natans, Nelumbo nucifera* and *Nymphoides peltatum*. The thick stands of emergents like *Phragmits australis* (tall ecotype) and *Typha angustata* at this site formed the most suitable breeding sites for mallard, white-eyed pochard and coot until 1921[46]. However, at present the chief colonizers of the wetlands are *Trapa natans, Potamogeton natans* and *Nymphoides peltata. Nelumbium nucifera* has now completely vanished from the wetland and likewise *P. australis* is almost getting replaced by *Sparganium erectum*. Similar situation has reached in Haigam wetland also. Surprisingly, pollution tolerant species like *Myriophyllum verticillatum* and *Hydrocharis dubia* have come up at certain sites in isolated patches of their own. Above all, in Hokersar, a perennial but protected wetland of Kashmir, the number of macrophytic species has declined considerably from 85 in 1963 to 24 in 1980[9, 13, 17, 38], and thereafter increased to 46 in 2005 due to the improvement of flood conditions[22]. However, species like *Barbera vulgaris, Juncus glaucus, Euryale ferox, Acorus calamus, Nelumbo nucifera* etc, as reported by some previous workers, were not recorded at all during the present study- a noteworthy feature. It is quite possible that these species might have disappeared from the so called "queen wetland" of Kashmir for the possible reason of greater anthropogenic pressures in the recent past[23].

Macrophytes and Eutrophication

Macrophytes, through their form, behaviour and resistance, influence pollution in different ways[47-51]. Besides causing pollution in some ways, they also remove pollutants and purify water to a certain extent. Varshney[52], Ambasht[53] and Pandit[11, 36] used a number of macrophytes as bioindicators of water quality, and their studies were based on the kinds of species present,

number of species and biomass production. Considering the species of macrophytes recorded from Kashmir Himalayan waters, this type of study envisages *Sparganium erectum, Myriophyllum verticillatum, Potamogeton pectinatus* and *P. crispus* as indicators of severe pollution, and *Lemna* spp., *Salvinia natans, Sagittaria sagittifolia, Potamogeton lucens, P.pucillus, Polygonum amphibium, Phalaris arundinaceae, Alisma plantago- aquatica* and *Ranunculus* sp. as indicators of eutrophication[11, 36]. The total disappearance of *Chara* sp. and *Euryale ferox* and the gradual replacement of clear water species like *Myriophyllum spicatum* and *Potamogeton* spp. by more resistant species viz. *Elodea* (Syn; *Hydrilla*) sp. and *Ceratophyllum demersum*, typical of eutrophic habitats, are clear signs of racing eutrophication. The explosive growth of *Lemna-Salvinia* weed complexes, because of their high aggressive capacity, colonize sites rich in organic matter, and also the sidewater channels and lake littorals[54,55]. Kaul[56] correlated the development of *Lemna- Salvinia* association of *Ricciocarpus- Lemnetum, Spirodela-Lemnetum gibbae, Lemnetum trisulcale-Salvinietum natantis* with excessive eutrophication bringing about a shift in under-water vegetation and resulting in the replacement of *Potamogeton lucens* by more eutrophic *Ceratophyllum demersum*. The author further opined 15 plant species and 10 plant associations to be rare in Kashmir waters and further believed emergent reed-swamp communities to be more resistant to eutrophication. The thick mats of *Lemna minor, L.gibba, L.triuslca* and *Spirodela polyrhhiza* (duckweeds) and the extensive growth of water fern (*Salvinia natans*) dispersed through wind, water currents and boating, the latter encroaching even upon the lotus (*Nelumbo nucifera*) zone during the recent years in Dal and other eutrophic waterbodies are the positive signs of increasing eutrophication of Kashmir freshwater[57].

Faunal Diversity

Wetland consumers are those animals that live in or visit wetlands and are dependent on wetland habitats for food, refuge or breeding sites. In general, there is lack of information and research on wetland consumers, although they include many ecologically important species of mammals, birds, reptiles, amphibians, fishes and invertebrates. According to Gopal and Krishnamurthy[58] in South Asia a total faunal inventory of any wetland has never been completed and the most investigated region are those in Kashmir[9] and the Keoladeo Ghana National Park at Bharatpur in Rajasthan[59, 60]. However, there are many reports of zooplankton in shallow waterbodies.

Freshwater wetlands of Kashmir are rich in faunal diversity. They are well known for their avifauna and fish fauna, many of which reside in wetlands only temporarily. Large number of insects belonging to different taxonomic groups depends on freshwater wetlands for completing their life cycle though the adults are not dependent on them. Further, numerous planktonic and benthic organism represent all groups of invertebrates. Several amphibians and reptiles use wetlands as feeding or breeding grounds but only a few mammals depend significantly on wetland. The distribution pattern and composition of invertebrate fauna in wetlands has been worked out in details[9]. The dominant invertebrate taxonomic groups encountered in the wetlands, in general, are Mollusca, Annelida and Arthopoda (including Crustacea, Arachnida and Insecta, the last one being a combination of different adaptive forms belonging to Coleoptera, Hemiptera, Lepidoptera, Orthoptera, Odonata and Diptera. These animals play an important role in the trophic structure of wetlands[9, 30]. Community-wise the secondary producers can be divided into zooplankton, zoobenthos and macrofauna.

Zooplankton

The distribution, population and biomass of zooplankton in wetland ecosystems is determined by the availability of food resources in the form of phytoplankton and microbe- organic detritus complex as well as the associated environmental factors. Kashmir wetlands have been extensively studied for zooplankton[9] and a number of publications have appeared since then[25, 30, 61, 62]. The 141 species of zooplankton, encountered during 1980 (Table 6) in five typical wetlands of Kashmir (Nowgam, Malgam, Haigam, Mirgund and Hokersar) include 51 Crustacea (35 cladocerans, 13 copepods and 3 ostracods), 29 Rotifera and 61 Protozoa (42 rhizopods, 17 ciliates and 2 zooflagellates). Seasonal variation in the density and biomass of zooplankton showed two peaks, one in late-spring and the other in autumn. The low population of zooplankton during the ice-covered periods and the rareness of *Diaptomus* and *Daphnia* species during the recent years are among the most striking features. However, in Wular, the largest freshwater body in the Indian subcontinent, Rotifera formed the

largest group, with 20 genera in the Bandipore sector and 24 genera in the Watlab sector, followed by Protozoa and Cladocera with 11 and 5 genera respectively, and Copepoda with a single genus[63]. In all these wetlands, however, the decisive proportion of the zooplankton standing crop is due to Crustacea and Protozoa, the contribution of Rotifera being comparatively low. The population of zooplankton is generally low, presumably because of the sustenance of relatively lower concentrations of phytoplankton. Zooplankton shows two biomass peaks which are related to phytoplankton biomass peaks, and therefore, show a succession typical of phytoplankton-zooplankton communities[9, 14]. Pandit and Qadri[17] while studying the wetlands of Kashmir opined that severe floods often lead to an increase in rotifers particularly *Brachionus* sp. and *Keratella* sp. and ciliates in general, and were detrimental to the crustaceans. During the later studies on some shallow lakes like Anchar, Wular and Hokersar different workers have recorded comparatively lesser number of zooplankton species (Table 7). Siraj *et al.*,[64] also recorded a total of 65 zooplankters only encompassing 32 species of Rotifera, 28 species of Cladocera and 5 species of Copepoda during a year round study in 2002 on zooplankton community of Dal lake around floating gardens. On the whole, sequence of dominance of various groups in terms of population density was: Rotifera (54%) > Cladocera (39%) > Copepoda (7%). In another study Siraj *et al.*[65] recorded only 16 species of cladocerans from Shalabugh wetland belonging to Chydoridae (7), Daphnidae (4), Macrothricidae (2), Bosminidae (2) and Moinidae (1). In still another study Malik[66] reported a total of a still smaller number of zooplankton species totaling 26 and belonging to 18 genera from a wetland basin of Dal lake, Brari-nambal. In this wetland Rotifera contributed the maximum of 17 species, of which 9 belonged to family Brachionidae, 2 to Lecanidae, one each to Trichocercidae, Asplanchnidae, Synchatidae, Hexarthridae and Philodinidae. Bdelloids too made a contribution to this group. The group was followed by Copepoda with 6 species, of which 5 were represented by sub-order Cyclopoda. Nauplii also made a significant contribution to this class. Cladocera was represented by 3 species, all belonging to family Daphnidae.

Pandit[9] while studying the seasonal succession of zooplankton further indicated the cladocerans being usually succeeded by copepods which in turn give way to rotifers with marching eutrophication. Further eutrophication brings a shift in the size of the zooplankton as large sized crustaceans give way to the small sized ones in order to escape predation by predators which also increase in their density with racing eutrophication[14].

Zoobenthos

The zoobenthic communities of Kashmir Himalayan wetlands have been thoroughly investigated in relation to their distribution, density, biomass and trophic relations by Pandit[9] in his extensive studies on the trophic structure of some typical wetlands. The meiobenthos or microbenthos include 79 taxa, comprising Protozoa (70), Nemathelminthes (2), Rotifera (5), Porifera (1) and Bryozoa (1).The macrozoobenthos seems to be somewhat species- limited, with only 17 taxa belonging to Annelida (9), Arthropoda (4), and Mollusca (4).The benthic macroinvertebrate were qualitatively represented by 8 species of oligochaetes (*Tubifiex tubifex, Limnodrilus hoffmeisteri, Chaeotogaster diaphanous, Aelosoma hemprichi, Pristina* sp., *Stylaria* sp., *Amphichaeta* sp. and *Nias* sp.) and one species of Hirudinea (*Eropobdella octoculata*), 4 species of insects (*Chironomus* sp., Hydraenidae, *Corixa* sp.and *Notonecta undulata*) and 4 species of molluscs (*Lymnaea stagnalis, L.auricularia, L.columella* and *Promenetus exacuous*).

The seasonal succession of zoobenthos showed a predominance of Protozoa (30.7%-60.7% biomass) in spring, Annelida (17.2%-61.9% biomass) in summer, Protozoa (30.6%-58.5% biomass) again in autumn and Mollusca (14.0%-69.7% biomass) in winter. A comparison of zoobenthic biomass in different wetlands, calculated on the basis of mean biomass figures, revealed Mirgund to be highly productive, and about twice that of Hokersar. The productive potential of Haigam, Malgam and Nowgam were intermediate between the two extremes. However, annelids made a large contribution (45%-52%) to the standing crop at the Mirgund and Malgam sites whilst Protozoa and Mollusca were large contributors at the Hokersar and Haigam sites, respectively. Nowgam differed from the other sites in sustaining almost equal proportion of Annelida, Protozoa and Mollusca, with no particular group clearly dominating at the site[9, 10, 30, 68, 69]. However, in another study on Dal lake, Jan[70] reported 35 species belonging to 26 genera, 20 families, 9 orders and 5 classes and 3 phyla of macrozoobenthic animals being collected during 1984 and 1985. Their relative contribution showed oligochaetes to be the most dominant group constituting about 46.5% of zoobenthic population. This was followed by insects

Table 6 - List of zooplankton in Kashmir wetlands[9, 21].

S. No.		Kashmir wetlands (1980)*	Hokersar (2001)**
A	**PROTOZOA**		
I	**Rhizopoda**		
1	*Acanthocystis chaetophora*	P	P
2.	*Actinosphaerium eichornii*	P	P
3.	*Amoeba* sp.	P	P
4.	*A. limax*	P	-
5.	*A. proteus*	P	-
6.	*Amphizonella violacea*	P	-
7.	*Arcella discoides*	P	P
8.	*A. megastoma*	P	P
9.	*A. mitrata*	P	-
10.	*A. vulgaris*	P	P
11.	*Awerintzewia cyclostoma*	P	-
12.	*Bullinularia indica*	P	P
13.	*Capsellina* sp.	P	P
14.	*Centropyxis aculeata*	P	P
15.	*C. arcelloides*	P	P
16.	*C. aerophila*	P	P
17.	*C constricta*	P	P
18.	*C.ecornis*	P	P
19.	*C. hemisphaereca*	-	P
20.	*C. indica*	-	P
21.	*C. stellata*	-	P
22.	*Difflugia accuminata*	-	P
23.	*D. arcula*	-	P
24.	*D. lebes*	P	P
25.	*D. oblongata*	P	P
26.	*D. robescens*	P	P
27.	*D. tuberculata*	-	P
28.	*Euglypha compressa*	P	-
29.	*E. cristata*	P	P
30.	*E. laevis*	P	-
31.	*E. tuberculata*	P	P
32.	*Heleopera rosea*	P	-
33.	*Hyalosphenia papilio*	P	-
34.	*Lesquereusia modesta*	P	-
35.	*L. spiralis*	P	-
36.	*Mastigamoeba longifilum*	P	-
37.	*Nebela caudate*	P	P
38.	*N. dentistoma*	P	P
39.	*Paraquadrula irregularis*	P	P
40.	*Paraeuglypha reticulata*	P	P
41.	*Parmulina cyanthus*	P	-
42.	*Pelomixa plaustrus*	P	-
43.	*Pontigularia vas*	P	-
44.	*Pyxidicula operculata*	P	P
45.	*Tracheleuglypha dentata*	P	P
46.	*Thecamoeba verrucosa*	P	-
47.	*Trigonopyxis arcula*	P	P
48.	*Trinema* sp.	-	P
II	**Ciliata**		
49.	*Bursaria truncatella*	P	-
50.	*Campanella umbellaria*	P	-
51.	*Claucoma* sp.	P	-
52.	*Climacostomum virens*	P	P
53.	*Colpoda* sp.	P	P
54.	*Colpidium colpoda*	P	-
55.	*Epistylis plicatilis*	P	-
56.	*Euplotes patella*	P	P
57.	*Holophyra simplex*	P	P
58.	*Opisthotricha procera*	P	P
59.	*Paramecium aurelia*	P	P

S. No.		Kashmir wetlands (1980)*	Hokersar (2001)**
60.	*P bursarıa*	P	-
61.	*P caudatum*	P	-
62.	*Porodon teres*	P	P
63.	*Pseudoporodon ellıpiticus*	P	P
64.	*Stentor roselı*	P	P
65.	*Urocentrum* sp.	-	P
66.	*Vortıcella campanula*	P	P
III	**Zooflagellates**		
67.	*Monas* sp.	P	P
68.	*Paramastix conıfera*	P	-
69.	*Physomonas* sp.	-	P
70.	*Placocısta spinosa*		
B	**ROTIFERA**		
71.	*Asplanchna priodonta*	P	-
72	*Brachionus bıdentata*	P	-
73.	*B. calyciflorus*	P	-
74.	*B. quadrıdentata*	P	P
75.	*Cephalodella* sp.	P	-
76.	*Colurella bıcuspidata*	P	P
77.	*Dıploıs* sp.	P	P
78.	*Epıphanes* sp.	P	-
79.	*Euchlanis dılata*	P	-
80.	*Fılına opoliensis*	P	-
81.	*Gastropus stylifer*	P	-
82.	*Horaella* sp.	P	-
83.	*Keratella cochlearis*	P	P
84.	*K. quadrata*	P	P
85.	*K valga*	P	P
86.	*Lecane luna*	P	-
87.	*L. ohioensis*	P	-
88.	*Monostyla bulla*	P	P

S. No.		Kashmir wetlands (1980)*	Hokersar (2001)**
89.	*M.lunaris*	P	P
90.	*Mytilına mucronata*	P	-
91.	*Notholca acuminata*	P	-
92.	*Philodina* sp.	P	-
93.	*Platyıas* sp.	P	-
94.	*Polyarthra vulgaris*	P	-
95.	*Pompholyx* sp.	P	-
96.	*Synchaeta pectınata*	P	P
97.	*Trichocera cylindrıca*	P	-
98.	*T. longiseta*	P	-
C	**CRUSTACEA**		
I	**Cladocera**		
99.	*Acroperus harpae*	P	-
100.	*Alona affinis*	P	P
101.	*A. intermedia*	P	-
102.	*A. karua*	P	P
103.	*A. quadrangularis*	-	P
104.	*Alonella dentıfera*	P	-
105.	*A. exigua*	P	-
106.	*A globulosa*	P	-
107.	*Bosmina coregoni*	P	P
108.	*B. longirostris*	P	-
109.	*Camptocercus rectirostris*	P	-
110.	*Ceriodaphnia laticaudata*	P	-
111.	*C. reticulata*	P	-
112.	*Chydorus barroisi*	P	-
113.	*C. gibbus*	P	-
114.	*C. ovalis*	P	-
114.	*C. ovalis*	P	-
116.	*Daphnia magna*	P	-
117.	*D. middendorffiana*	P	-
118.	*D. pulex*	P	P

S. No.		Kashmir wetlands (1980)*	Hokersar (2001)**
119.	*D. rosea*	P	P
120.	*Eurycerus lamellatus*	P	-
121.	*Graptolebris testudinaria*	P	-
122.	*Ilyocoryptus acutifrons*	P	-
123.	*Leydigia quadrangularis*	P	-
124.	*Macrothrix rosea*	P	-
125.	*Moina affinis*	P	P
126.	*Monospilus dispar*	P	-
127.	*Pleuroxus denticulatus*	P	-
128.	*Pseudosida bidentata*	P	P
129.	*Scapholebris aurita*	P	-
130	*S. kingi*	P	-
131.	*Sida crystallına*	P	P
132.	*Simocephalus exspinosus*	P	-
133.	*S. vetulus*	P	-
II	**Copepoda**		
134.	*Bryocamptus arictus*	P	-
135.	*B.minutus*	P	-
136.	*Canthocamptus* sp.	P	-
137.	*Cyclops bicolor*	P	P
138.	*C. bicuspidatus*	P	P
139.	*C. scutifer*	P	-
140.	*C. venustum*	P	-
141.	*C. vernalis*	P	P
142.	*Diaptomus* sp.	P	-
143.	*Eucyclops agılis*	P	-
144.	*Macrocyclops albidus*	P	-
145.	*Macrocyclops* sp.	-	P
146.	*Mesocyclops hyalinus*	P	P
147.	*Paracyclops fimbriatus*	P	-
III	**Ostracoda**		
148.	*Cyperus* sp.	P	-
149.	*Eucypris hystrix*	P	P
150.	*Physocypris posterotuberculata*	P	-

Table 7 - Total number of zooplankton species recorded from Anchar[67], Wular[42] and Hokersar[21].

Taxonomic group	Anchar lake (2001)	Wular lake (2006)	Hokarsar wetland (2001)
Protozoa	33	8	45
Rotifera	13	11	9
Crustacea	22	15	16
Total	68	34	70

and molluscs contributing 26.9% and 19.6% respectively. Crustacean contribution was the least.

Macrofauna

The wetlands provide habitats for a variety of amphibious animals which are associated with the dense micro-and macrophytic vegetation. The damage caused to plants by these animals is often severe[9, 71].

A detailed faunistic study of the Kashmir wetlands was carried out by Pandit[9] and a number of publications have appeared thereafter[30, 45, 72]. The wetland macrofauna can be recognized as falling into two categories : (i) permanent fauna, and (ii) temporary fauna (i.e. occasional visitors like migratory birds and mammals). According to the author the first category, comprising 45 taxa most of which are euryecious, include both macro-invertebrates such as Mollusca, Annelida, Arthropoda and vertebrates like fishes and amphibians. (Table 8)

Invertebrates

The maximum development of invertebrates in terms of density, growth and biomass during the warm-

Table 8 - Distribution of macrofauna in wetlands of Kashmir by food source[9].

I.	Permanent Macrofauna (Native)	II.	Temporary Macrofauna (Occasional Visitors)
(A)	**Herbivores**	(A)	**Herbivores**
I	Arthropoda (Insects)	I	Aves (Birds)
	Hydrophilus sp. *		*Anas pltyrhynchos* (Wild mallard)
	Hydraenidae *		*A. crecca* (Common teal)
	Epicauta sp.		*A. discors* (Blue- winged teal)
	Corixa sp.		*A. acuta* (Pintail)
	Hyalopterus prunii o		*A. stepera* (Gadwall)
	Rhopalosiphum nymphae o		*A americana* (Wigeon)
	R. myadis o		*Spatula clypeata* (Shoveler)
	Lepidoptera		*Aytha rufa* (Pochard)
	Melanoplus sp.		*Fulica atra* (Coot)
	Culicidae (adult)		*Anser anser* (Wild goose)
	Chronomidae (larva) *		*Anser* sp. (Domestic goose)
	Rhagonoidae		
	Tipula sp. **		
II	Mollusca (Snails)		
	Lymnaea stagnalis *		
	L. auricularia *		
	L. columella *		
	Promenetus exacuous *		
	Planorbis sp. *		
III	Pisces (Fishes)		
	Cyprinus carpio (adult) *		
	Puntius conchonius		
(B)	**Omnivores**	(B)	**Omnivores**
I	Arthropoda	I	Aves (birds)
	Gammarus sp. (freshwater shrimp)		*Anas platyrhynchos domestica* (Domestic duck)
	Noteridae		*Gallinula chloropus parvifrons* (Moorhen)
	Acheata assimilis		*Hydrophasianus chirurgus* (Pheasant-tailed jacana)
	Culicidae (larvae)		*Rhipidura pectoralis* (White-browed fantail fly catcher)
II	Annelida		*Carpodacus erythrinus* (Rose finch)
	Pheretima sp. (earth worm) **		
III	Pisces (Fishes)		
	Cyprinus carpio (fry)		
	C. carpio (fingerling)		

I.	Permanent Macrofauna (Native)	II.	Temporary Macrofauna (Occasional Visitors)
III	Amphibia		
	Tade poles		
(C)	**Carnivores**	(C)	**Carnivores**
I	Arthropoda	I	Aves (birds)
	Araneae o		*Ardea cinerea* (Grey heron)
	Acari		*Ardeola grayi* (Pond heron)
	Silpha sp. **		*Podiceps ruficollis albipennis* (Dabchick)
	Dytiscus marginalis		*Rhipidura pectoralis* (White spotted fantail flycatcher)
	Nepa sp.		*Alcedo atthis* (Common king-fisher)
	Anisoptera		*Moticilla citreola citreoloides* (Yellow headed wagtail)
	Zygoptera		*M. cinerea melanope* (Little bittern)
	Ephydra sp. *		*M. alba hogsoni* (White wagtail)
	Tubifera sp.		*Ixobrychus minutus* (Little bittern)
II	Annelida		*Chilodonias leucopareia indica* (Whiskered tern)
	Glossiphona sp. o	**(D)**	**Top carnivores**
III	Pisces	I	Aves
	Cyprinus carpio (newly hatched fly)		*Milvus migrans* (Common kite) ***
	Gambusia affinis		*Pseudogyps bengalensis* (White backed vulture) ***
	Rana cyanophlectus		*Neophron percnopterus* (Egyptian vulture) ***
		II	Mammalia
	Bufo viridis		Mongoose

o Parasitic types

** Largely detritivores

* Slightly detritivores also

*** Scavenger types

water period can be explained on the basis of better trophic conditions, and the provision of suitable breeding and sheltering sites provided by the profuse growth of various macrophytic species. Further, the shallow wetlands tend to warm quickly to relatively high temperatures, which itself results in the enhancement of reproduction[73].The availability of unlimited food coupled with warm water conditions seems to be the most plausible explanation for the existence of high numbers of individuals of macro-invertebrates during the warm-water period. Conversely, the winter minimum is attributed to the high morality of fauna during periods with cold temperatures and the shortage of food supplies[9].

Fish

The wetlands particularly Wular lake, have great potential as fisheries and provide a livelihood for fishermen in the bordering villages. The fish resources of the lake comprise both endemic as well as exotic species. Fishes namely *Schizothorax curvifons* (Sattar Gad), *Schizothorax esocinus* (Cherru), *Schizothorax niger* (Aile Gad) and *Schizothorax planifzons* (Cha-ush Gad) are the endemic forms ; while *Cyprinus carpio specularis* (mirror carp) and *Cyprinus carpio cummunis* (scale carp) are the exotics to the lake. The total fish production of Wular Lake during March 2005 - February 2006 has been estimated to be 7.50 thousand tonnes against 6.21 thousand tonnes recorded from March 2000-

February 2001[42]. While the fisheries potential of typical wetlands has not yet been properly exploited, Pandit [9, 74] estimated a maximum standing crop of 20.0 g/m^2-56.6 g/m^2 in different wetlands of Kashmir. The author is of the opinion that the snow fish (*Schizothorax* spp.) has completely disappeared from the five typical wetlands due to the shallow nature and high trophic status of these biotopes[74]. Contrarily, four species of hardy carp (*Cyprinus carpio communis, C.c specularis, Puntius conchonius* and *Gambusia affinis*) flourish in these ecosystems. The study further reveals that *C.c. communis* is the main fish in Nowgam, Haigam, Mirgund and Hokersar where the mirror carp (*C.c.specularis*) seems to be limited, but is rather more abundant in Malgam and Hokersar. *Puntius conchonius*, though poorly represented, is more abundant in the Malgam wetland. A comparison of fish biomass in five different wetlands revealed Mirgund to be most productive and Nowgam least productive; Haigam, Malgam and Hokersar are intermediates. There is no historical information available regarding the depletion of fish resources in Kashmir wetlands but it is clear that during drought, which mostly occurs in autumn, these biotopes are subjected to large scarcity of water, as a consequence of which the benthic fauna, fish and other animals are vulnerable to predation by dogs, kites, vultures, mongoose and other carnivorous animals. Overall the fish resources of the typical wetland have declined considerably.

Amphibians

Only two species of amphibians, *Rana cyanophlyctis* and *Bufo viridis*, have been identified in the sub-temperate wetlands of the Kashmir Himalaya. In winter, a period of restricted growth, these amphibians burrow deep into the mud for hibernation and are thus commonly encountered in very small numbers. The skipper frog (*Rana cyanophlyctis*), confined exclusively to water, is more abundant in Malgam even in winter, probably because of warm water conditions maintained by the influence of spring-fed waters. There has been a gradual amphibian decline; during the last three decades in the valley as well as the wetlands.

Birds

The most conspicuous aspect of different wetlands is their rich avifauna. Wetlands are attractive to numerous bird species for various reasons, the most important of which is the abundance of food, especially in the littorals. In addition, wetlands provide relatively safe areas for roosting or moulting, and because the number of wetlands is limited, the number of birds there is often enormous.

Waterfowl population and their feeding habits and habitat use in Kashmir wetlands have been extensively studied [9, 10, 12, 75, 76, 77]. These wetlands provide overwintering resorts for about 0.3 million wild ducks geese and rails migrating from their breeding grounds in the Palaearctic region, extending from north Europe to central Asia, and breeding and nesting grounds to a host of other birds in summer. More than 45 species of birds including residents, summer migrants and winter migrants are encountered in these wetlands. Among the common waterfowl (13 species in total) that inhabit some important wetlands in Kashmir from early September to end of April are (i) the dabbling ducks like mallard (*Anas platyrhynchos*), common teal (*A. crecca*), garganey or blue- winged teal (*A.querquedula*), pintail (*A.acuta*), gadwall (*A.strepera*),wigeon (*A. penelope*), shoveller (*Spatula clypeata*), and ruddy or shelduck or brahminy duck (*Casarca ferruginea*); (ii) rails such as coot (*Fulica atra atra*); and (iii) greylag goose (*Anser anser*). Common snipe (*Capella gallinago*) is also found in these biotopes and is most abundant in the Malgam wetland. Jamwal[78] also reports that until the late 1950s, seven species of dabbling ducks, two of shelduck, four of geese, one of swan, six pochard and two mergansers, a total of 22 species, were regularly recorded wintering in the valley. Based on the published data, however, a total of 25 species of ducks and geese have shown their occurrence in the Kashmir waters and three species viz. gargney, tufted duck, and white eyed pochard, have shown irregular visits to Kashmir in recent years. Further, Pandit[9] did not observe 6 important wildfowl species recorded earlier by various workers, which are: Cotton Teal[79]; Spotbill Duck[80] Snow Goose[81]; Canada Goose[82]; White-headed Stiff-tailed Duck and White-eyed Pochard (breeding bird[83]). These observations are in conformity with the findings of Zargar and Naqash[84] and Bacha[85, 86] who recorded only 13 species of Anatids from Kashmir during the recent years in an organized censes conducted during the years 1992, 93 and 94 by the Wildlife Protection Department, J and K Govt.[34]. The galaxy of more than 32 species of other birds which breed and nest in these wetlands include moorhen (*Gallinula chloropus*

parvifrons), little bittern (*Ixobrychus minutus*), pheasant tailed jacana (*Hydrophasianus chirurgus*), whiskered tern (*Chilodonias leucopareia*), Indian wren-warbler (*Prinia inornata*), rosefinch (*Carpodacus erythrinus*), white-spotted fantail flycatcher (*Rhipidura pectoralis*), white-browed fantail flycatcher (*R.aureola*), common kingfisher (*Alcedo atthis*), yellow-headed wagtail (*Motacilla citreola citreoloides*),white wagtail (*M. alba hogsoni*), grey wagtail (*M.cinerea melanope*), grey heron (*Ardea cinerea*), pond heron (*Ardeola grayi*) and little grebe or dabchick (*Podiceps ruficollis albipennis*).

The waterfowl concentration in some protected wetlands like Hokersar and Haigam has developed as a result of the deterioration in habitat quality of the formerly important migration areas like Mirgund, Krachu, Malangpora, Narkora, Nowgam, Malgam, Shalabogh and the littorals of Dal, Anchar and Wular lakes[12, 76, 77, 87]. The carrying capacity of these wetlands as wildlife habitats has of late been greatly altered mainly because of the accelerated human impacts, making the future bleak for waterfowl. These are reports that in the past, the waterfowl population was larger than at present and the wetlands were deep enough for diving ducks, but as a consequence of changing hydrological regimes brought about by floods which have varied frequency, duration and amplitude, and of about altered vegetation patterns, the migratory waterfowl no longer breed in the wetlands as they did before 1921. Osmaston[88] and Bates and Lowther[46] have reported impressive assemblages of wintering waterfowl and an abundance of breeding mallard, common pochard and coot in the wetlands of Kashmir. It is difficult to believe that at one time boatloads of both mallard and pochard eggs were sold in the markets of Srinagar. These species breed in large numbers in Dal, Anchar, and other lakes during the months of May and June. The wetlands are now used only as wintering grounds for large flocks of waterfowl. Similarly, the population of greylag goose (*Anser anser*) has started to decline because *Phragmites australis*, a favourite food of this bird, is gradually losing ground in Hokersar and is being replaced by *Sparganium erectum*[12, 76].

Mammals

Jamwal[78] reported only two resident mammals as occurring in wetlands of Kashmir, namely the freshwater otter (*Ludra ludra*) and the harvest mouse (*Micromys minutus*) and noticed a sharp decrease in the numbers of the former during the last five years. However, Pandit[9] noticed a high degree of predation on frogs by mongoose in the Malgam wetland, which has a typical prairie appearance. Other occasional visitors include a large population of cows, sheep and horses, especially in unprotected wetlands like Nowgam, Malgam and Mirgund, subjecting them to large grazing pressures[9, 87].

References

1. Wharton CH. The Southern River Swamp- A Multiuse Environment. Atlanta : Georgia State University, 1970.
2. Odum EP. Fundamentals of Ecology. Third edition, Philadelphia: Saunders, 1971.
3. Corner WH, Day JW. Productivity and composition of bald cypress- water tupelo site and a bottom land hardwood site in a Louisiana freshwater swamp. *Amer J Bot* 1976; **63** : 1354-1364.
4. Gopal B. The role of ecotones in the conservation and management of tropical inland waters. *Mittelungen International a vereingung Limnologie* 1994; **24** : 17-25.
5. Handoo JK. Ecological and production studies of some typical wetlands of Kashmir Ph. D. Thesis. University of Kashmir, Srinagar, 1978.
6. Handoo JK, Kaul V. Phytosociological and standing crop studies in wetlands of Kashmir. In : Gopal B, Turner RE, Wetzel RG, Whigam DF, editors. Wetlands: Ecology and Management, part 1. Jaipur, India: National Institute of Ecology and International Scientific Publication, 1982. pp. 187-197.
7. Kaul S. Contribution to the analysis of some wetland ecosystems of Kashmir with reference to biogeochemical·cycling. Ph D. Thesis, University of Kashmir, Srinagar, 1979.
8. Kaul S. Community architecture, biomass and production in some typical wetlands of Kashmir. *Ind J Ecol* 1982; **9** : 320-329.
9. Pandit AK. Biotic factor and food chain structure in some typical wetlands of Kashmir. Ph D. Thesis, University of Kashmir, Srinagar, 1980.
10. Pandit AK. Feeding ecology of breeding birds in five wetlands of Kashmir. *Ind J Ecol* 1982; **9 (2)** : 181-190.
11. Pandit AK. Role of macrophytes in aquatic ecosystems and management of freshwater resources. *J Environ Management* 1984; **18** : 73-88.
12. Pandit AK. Threats to Kashmir wetlands and their wildlife resources. *Environ Conservation* 1988; **15 (3)** : 266-268.

13. Pandit AK. Conservation of wildlife resources in wetland ecosystems of Kashmir, India. *J Environ Management* 1991; **33 (2)** : 143-154.

14. Pandit AK. Freshwater Ecosystem of the Himalaya. New York, London: Parthenon Publishing, 1999.

15. Pandit AK. Plant diversity in freshwater ecosystems of Northwest Himalaya. *J Res Dev* 2001; **1** : 1-22.

16. Pandit AK. Freshwater biological resources of Kashmir Himalaya. In: Pandit AK, editor. Natural Resources of Western Himalaya. Srinagar : Valley Book House, 2002.

17. Pandit AK, Qadri SS. Floods threatening Kashmir wetlands. *Jour Environ Management* 1990; **31 (4)** : 299-311.

18. Kak AM. Aquatic and wetland vegetation of Kashmir Himalaya. *J Econ Taxon Bot* 1990; **4** : 1-14.

19. Khan MA. Environmental Biodiversity and Conservation. New Delhi: APH. Publishing House, 2000.

20. Gangoo SA, Makaya AS. Changes in vegetation pattern of Hokersar (wetland reserve), Kashmir. In: Khan MA, editor. Environmental Biodiversity and Conservation. New Delhi: APH Publishing House, 2000. pp. 107-112.

21. Rather SA. Plankton dynamics in Hokersar, a typical wetland of Kashmir. M Phil Dissertation, University of Kashmir, Srinagar, 2001.

22. Kumar R, Pandit AK. Community architecture of macrophytes in Hokersar wetland, Kashmir. *Ind J Environ and Ecoplan* 2005; **10 (3)** : 565-573.

23. Pandit AK, Kumar R. Comparative studies on ecology of Hokersar wetland, Kashmir: Present and past. *J Himalayan Ecol and Sustain Dev* 2006; **1** : 73-81.

24. Kumar R, Rather GH, Pandit AK. Primary productivity of dominant macrophytes in Hokersar, a perennial wetland in Kashmir Himalaya. *J Himalayan Ecol Sustain Dev* 2007; **2** : 33-36.

25. Kaul V, Fotedar DN, Pandit AK, Trisal CL. A comparative study of plankton populations in some typical freshwater bodies of Jammu and Kashmir State. In: Sen DN, Bansal RP, editors. Environmental Physiology and Ecology of Plants. Dehradun: B. Singh, MP Singh, 1978. pp. 249-269.

26. Trisal CL. Ecology and conservation of Dal lake Kashmir. *Water Resour Dev* 1987; **3 (1)** : 44-54.

27. Kant S, Kachroo P. Limnological studies in Kashmir lakes-I. Hydrobiological features, composition and periodicity of phytoplankton in the Dal and Nageen lakes. *Phykos* 1977; **16 (1, 2)** : 77-97.

28. Pandit AK, Pandit SN. Ecological studies of periphyton in two lakes of Kashmir Himalaya. In: Misra SR, editor. Assessment of Water Pollution. New Delhi: APH Publishing Corporation, 1996.

29. Bhat SA, Pandit AK. Phytoplankton studies in Anchar lake, Kashmir. In: Kumar A, editor. Ecology of Plankton. Delhi: Daya Publishing House, 2005.

30. Pandit AK, Kaul V. Trophic structure of some typical wetlands. In: Gopal B, Turner RE, Wetzel RG, Whighman DF, editors. Wetlands-Ecology and Management. Jaipur: *Nat Inst Ecol and Int Sci Publi,* 1982. pp. 55-82.

31. Pandit AK. Macrophytic vegetation in freshwater ecosystems of Kashmir Himalaya. *Oriental Science* 1998; **3 (2)** : 43-58.

32. Rather SA, Pandit AK. Phytoplankton dynamics in Hokersar wetland, Kashmir. *J Res Dev* 2002; **2** : 25-46.

33. Kant S, Vohra S. Algal flora of J and K State, *J Indian Bot Soc* 1999; **78** : 51-64.

34. Dar GH, Bhagat RC, Khan MA. Biodiversity of the Kashmir Himalaya. Srinagar: Valley Book House, 2002.

35. Kaul V, Trisal CL, Handoo JK. Distribution and production of macrophytes in some waterbodies of Kashmir. In: Singh JS, Gopal B, editors. Glimpses of Ecology. Jaipur: *Intt Sci Publications*, 1978. pp. 313-334.

36. Pandit AK. Macrophytes as a component of Dal lake ecosystem. In: Mishra SR, Saksena DN, editors. Aquatic Ecology. New Delhi: Ashish Publishing House, 1992. pp. 45-67.

37. Pandit AK. Biodiversity in freshwater ecosystems of North-West Himalayas. In : Rawat JK, Srivastava SK, Biswas S, Vasistha HB, editors. Conservation of Biodiversity in India- Status, Challenges and Efforts. Dehradun: Indian Council of Forestry Research and Education, 2005.

38. Kaul V, Zutshi DP. A study of aquatic and marshland vegetation of Srinagar lakes. *Proc Nat Inst Sci, India*, 1967; **33** : 111-128.

39. Lawrence WR. The Valley of Kashmir. Srinagar: Chinar Publishing House, 1967.

40. Arber A. Water Plants. Cambridge: Cambridge University Press, 1920. pp. 1-436.

41. Sculthorpe CD. The Biology of Aquatic Vascular Plants, London : Arnold, 1967. pp. 1-610.

42. Mir SS. Trophic status of Wular lake, Kashmir, Ph D. thesis. University of Kashmir, Srinagar, 2006.

43. Rather GH, Pandit AK. Diversity of emergent macrophytes in two rural lakes of Kashmir Himalaya. *J Res Dev* 2005; **5** : 71-77.

44. Rather GH, Kumar R, Pandit AK. Distribution of aquatic vegetation in Ahansar, a fresh water lake in Kashmir Himalaya. *J Res Dev* 2007; **7** : 39-44.

45. Kaul V, Pandit AK, Fotedar DN. Ecology of freshwater snails (gastropod molluscs) in Haigam, a typical wetland of Kashmir. *Trop Ecol* 1980; **21 (1)** : 32-46.

46. Bates RSP, Lowther EHN. Breeding Birds of Kashmir. London: Oxford University Press, 1952.

47. Lange L, Zon JC. Proposal for a numerical description of the development of aquatic macrophytic vegetation as an aid for the assessment of water quality. *Wass Abwss* 1973; **4** : 1-4.

48. Rajmankova E. Comparison of *Lemna gibba* and *Lemna minor* from the production ecology view point. *Aquat Bot* 1975; **1** : 423-427.

49. Hejney S, Husak S. Higher plant communities. In: Dkyjova D, Kvet J, editors. Pond Littoral Ecosystems. New York: Springer - Verlag. 1978.

50. Clark JR, Messenger DE, Dickson KL, Cairns J. Simultaneous extraction of ATP and chlorophyll from aufwuchs communities. *Limnol Oceanogr* 1978; **23** : 1955-1059.

51. Marven P, Komarek JK, Ettl H, Komarkove J. Structure elements and principle populations of algae. Spatial distribution. In: Dkyjova D, Kvet J, editors. Pond Littoral Ecosystem. New York: Springer- Verlag, 1978.

52. Varshney CK. Macrophytes as indicators of water quality. In : Zaffar AR, Khan KR, Khan MA, Seenayya G, editors. Proceedings of the Workshop on Biological Indicators and Indices of Environmental Pollution. Hyderabad: Cent Bd Prev Cont Water Poll/ Osmania Univ, 1981. pp. 53-59.

53. Ambasht RS. Responses of aquatic plants to pollution. In : Zaffar AR, Khan KR, Khan MA, Seenayya G, editors. Proceedings of the Workshop on Biological Indicators and Indices of Environmental Pollution Hyderabad: Cent Bd Prev Cont Water Poll/ Osmania Univ. 1981. pp 61-66.

54. Kaul V, Bakaya U. *Lemna-Salvinia*, the noxious floating aquatic weed complex in Kashmir. In : Varshney CK, Rzoska J, editors. Aquatic Weeds of South-east Asia. The Hague: W. Junk, 1973.

55. Pandit AK, Kaul V, Fotedar DN. A preliminary study of duckweed ecology and its natural control. *Int J Ecol Environ Sci* 1978; **4** : 107-115.

56. Kaul V. Conservation of plant resources in aquatic ecosystems with reference to some aquatic habitats of Kashmir. In: Jain SK, Mehra KL, editors. Conservation of Tropical Resources. Kolkata, New Delhi: Botanical Survey of India and DOE, 1984. pp. 118-131.

57. Kaloo ZA, Pandit AK, Zutshi DP. Nutrient status and phytoplankton dynamics of Dal lake under *Salvinia natans*, an obnoxious weed growth. *Oriental Science* 1995; **1** : 73-85.

58. Gopal B, Krishnamurthy K. Wetlands of South Asia. In: Whigham DF et al., editors. Wetlands of the World. Netherlands: Kluwer Academy Publishers, 1993. pp. 345- 414.

59. Salim Ali, Vijayan VS. Keoladeo National Park: Ecology Study, Summary report 1980-1985. Bombay: Bombay Natural History Society, 1986.

60. Vijayan VS. Keoladeo National Park: Ecology Study- Annual Report 1987. Bombay: Bombay Natural History Society, 1988.

61. Kaul V, Pandit AK. Is Dal lake dying? *Science Reporter* (CSIR) 1979; **16 (11)** : 734-736.

62. Kaul V, Pandit AK. Biotic factor and food chain structure in some typical wetlands of Kashmir. *Poll Res* 1982; **1**: 49-54.

63. Moza U. Zooplankton composition and fluctuation in Wular lake, Kashmir. In : Yousuf AR, Raina MK, Qadri MY, editors. Current Trends in Fish and Fishery Biology and Aquatic Ecology. Srinagar: University of Kashmir, 1992. pp. 239-244.

64. Siraj S, Yousuf AR, Bhat FA, Parveen M. Impact of floating gardens on the water quality and zooplankton community in Dal lake, Kashmir *J Res Dev* 2006; **6** : 25-34.

65. Siraj S, Yousuf AR, Parveen M. Cladoceran community in Shalabugh wetland, Kashmir. *J Res Dev* 2007; **7** : 67-74.

66. Malik AA. Water quality of Brari Nambal basin of Dal lake. M Phil. dissertation, University of Kashmir, Srinagar, 2004.

67. Bhat SA. Plankton dynamics in Anchar lake of Kashmir. M Phil. Dissertation. University of Kashmir, Srinagar. 2001.

68. Kaul V, Pandit AK. Benthic communities as indicators of pollution with reference to wetlands of Kashmir. In: Zaffar AR, Khan KR, Khan MR, G. Seenayya, editors. Proceedings of the WHO Workshop on Biological Indicators and Indices of Environmental Pollution. Hyderabad: Cent Bd Prev Cont Water Poll/Osmania University, 1981. pp. 33-52.

69. Pandit AK, Qadri MY, Jan U. Benthic communities of inland waters of India. In : Shastree NK, editor. Current Trends in Limnology. Delhi: Narendra Publishing House, 1991. pp. 237-250.

70. Jan U. Studies on macrozoobenthos of Dal lake. Ph D. Thesis, University of Kashmir, Srinagar, 1987.

71. Pandit AK, Pandit SN, Kaul V. Ecological relation between invertebrates and submerged macrophytes in the Himalayan lakes. *Poll Res* 1985; **4 (2)** : 53-85.

72. Pandit AK. Ecology of insect community in some typical wetlands of Kashmir Himalaya. In : Yousuf AR, Raina MK, Qadri MY, editors. Current Trends in Fish and Fishery Biology and Aquatic Ecology. Srinagar: University of Kashmir, Srinagar, 1992. pp. 271-286.

73. Gallup DN, Vander Giessen P, Boerger, H. A survey of plankton and bottom invertebrates of the peace- Athabasea Delta Region, *Canadian Wildlife Service* 1971; p. **36**.

74. Pandit AK. Ecology of fishes in wetland ecosystems of Kashmir with emphasis on their management. In : Durga Prasad MK, Pitchaiah PS, editors. Inland Water Resources-India. Delhi: Discovery Publications, 1997. pp. 188-201.

75. Pandit AK. Feeding ecology of wild ducks and geese over-wintering in wetlands of Kashmir Himalaya. *Ind J Ecol* 1989; **16 (2)** : 199-202.

76. Pandit AK. Conservation of wildlife resources in wetland ecosystems of Kashmir India. *J Environ Manage* 1991; **33** : 143-154.

77. Pandit AK. Lakes in Kashmir Himalaya. In: Khan AH, Pandit AK, editors. Ecology, Environment and Energy. Srinagar: University of Kashmir, 1996. pp. 1-40.

78. Jamwal KKS. Wetland Kashmir. *Sanctuary* 1991; **11** : 26-33.

79. Mitchell FJ. Cotton teal, (*Nettapus coromandelianus*) in Kashmir. *J Bombay nat Hist Soc* 1914; **23 (12)** : 584.

80. Oliver GG. Spot- bill Duck in Kashmir, *J Bombay Nat Hist Soc* 1919; **26 (2)** : p. 675.

81. Ali S, Setna SB, Santapu H. The snow goose (*Anser hyperborcus pallas*) in Kashmir - in addition to the avi-fauna of India. *J Bombay Nat Hist Soc* 1950; **49 (2)** : 311-12.

82. Yocum CF. Evidence of Canada Geese in Kashmir, India. *Murrelet* 1970; **1** : 15- 26.

83. Ali S, Ripley SD. Compact Handbook of Birds of India and Pakistan together with those of Bangladesh, Nepal, Bhutan and Sri Lanka, Second edition. New Delhi: Oxford University Press, 1987.

84. Zargar AR, Naqash RY. Waterfowl Census report (March and February, 1993). Srinagar: Department of Wildlife Protection, 1993.

85. Bacha MS. Waterfowl Census in Kashmir Wetlands (February-April, 1992). Srinagar: Research and Survey Unit, Department of Wildlife Protection, J and K Govt. 1992.

86. Bacha MS. Waterfowl Census in Kashmir Wetlands (September 1992- April, 1993). Srinagar: Research and Survey Unit, Department of Wildlife Protection, J and K Govt. 1996.

87. Pandit AK, Fotedar DN. Restoring damaged wetlands for wildlife. *J Environ Management* 1982; **14** : 359-68.

88. Osmaston BB. Notes on the birds of Kashmir, *J Bombay Nat Soc* 1927; **32** : 134-153.

89. Kumar R. Changes in distribution and production of some macrophytes in Hokersar wetland, Kashmir. M Phil. Dissertation, University of Kashmir, Srinagar, 2003.

Proc. Nat. Acad. Sci. India, Sect. B, Vol. 78, Spl. Issue, 2008

Life of wetland cyanobacteria under enhancing solar UV-B radiation

R.P. SINHA***, R.P. RASTOGI, N.K. AMBASHT* and D.-P. HÄDER**

****Centre of Advanced Study in Botany, Banaras Hindu University, Varanasi-221005, India.*

**Department of Botany, Christ Church College, Kanpur, India.*

***Institute for Biology, Friedrich-Alexander University, Staudtstr. 5, D-91058 Erlangen, Germany.*

****e-mail : r.p.sinha@gmx.net*

Abstract

The continuing depletion of stratospheric ozone layer mainly due to anthropogenically released pollutants such as chlorofluorocarbons (CFCs) has resulted in an increase in solar ultraviolet-B (UV-B: 280 - 315 nm) radiation reaching to the Earth's surface. UV-B is a small (less than 1% of total energy) but highly active component of solar radiation that can penetrate deep into biologically significant depths in lakes, ponds, rivers and oceans. Photosynthetic prokaryotes such as cyanobacteria are dependent on solar energy and thereby always sense and face the stress of UV-B radiation. UV-B can cause wide ranging effects including mutagenesis, destruction of proteins/enzymes, inhibition of a number of vital metabolic processes and formation of thymine dimers in DNA leading to death of microbes. The degree of damaging effects brought about by UV-B varies in different species suggesting the existence of certain protective mechanisms operative in cyanobacteria. A number of species counteract the damaging effects of UV-B by synthesizing UV protective compounds such as mycosporine-like amino acids (MAAs) and the sheath pigment, scytonemin. These compounds are known to act as natural sunscreens and their synthesis is induced by UV-B radiation. In this article an attempt has been made to highlight some of the notable effects of UV-B radiation on wetland cyanobacteria and the role of photoprotective mechanisms in mitigating the damage.

Key words: mycosporine-like amino acids (MAAs), photoprotection, scytonemin, UV-B radiation, wetland, cyanobacteria

सारांश

मुख्यत मानवजनित मुक्त प्रदूपको जैसे क्लोरोफ्लोरोकार्बन के कारण लगातार समताप मण्डलीय परत के क्षय के परिणामस्वरूप पृथ्वी पर सौर परावैगनी–बी विकिरण (280 - 315 नेनोमीटर) की मात्रा बढी हे। परावैंगनी–बी अत्यन्त अल्प (सम्पूर्ण ऊर्जा का एक प्रतिशत से भी कम) किन्तु सौर–विकिरण का एक सक्रिय घटक है जो कि झरनो, तालावो, नदियो एव समुद्रो मे जैविक रूप से महत्वपूर्ण गहराई तक प्रवेश कर सकता है। प्रकाशसंश्लेषी प्रोकैरियोट जीव जैसे नील–हरित शैवाल (साइनोबैक्टीरिया) सौर ऊर्जा पर निर्भर होते है तथा पराबैगनी–बी विकिरण के प्रभाव का हमेशा अनुभव एव सामना करते है। पराबैगनी–बी विकिरण विस्तृत रूप से अपना हानिकारक प्रभाव, जैसे उत्परिवर्तन, प्रोटीन तथा एन्जाइम का विघटन, कई प्रमुख जैविक उपापचयी क्रियाओ का अवरोधन तथा डीएनए में थाइमीन द्विअणुओ का बनना, आदि प्रक्रियाओ पर डालता है। परिणामस्वरूप जीवाणुओं (सूक्ष्म जीवों) की मृत्यु हो जाती है। पराबैगनी–बी विकिरण के हानिकारक प्रभावों का असर सूक्ष्मजीवो की विभिन्न प्रजातियो मे भिन्न–भिन्न मात्रा मे होता है, जो सूक्ष्मजीवो मे कुछ निश्चित रक्षात्मक प्रक्रियाओ की मौजूदगी एव सम्पादित होने का सकेत देती है। कई सूक्ष्म जीव पराबैगनी–बी विकिरण के हानिकारक प्रभावो को सौर रक्षात्मक यौगिको जेसे मायकोस्पोरिन सदृश अमीनो अम्लो, आच्छद वर्णक, साइटोनेमिन आदि के सश्लेषण के द्वारा प्रभावहीन कर देते है। उपरोक्त यौगिको को प्राकृतिक सौर रक्षात्मक आवरण के रूप मे जाना जाता है जिनका सश्लेषण परा बैगनी–बी विकिरण के द्वारा प्रेरित होता है। इस अभिलेख मे आर्द्रभूमि में पाये जाने वाले नील–हरित शैवाल पर पराबैंगनी–बी विकिरण के विशिष्ट प्रभावो एव उनसे उत्पन्न हानि को कम करने के लिये प्रकाशरक्षी क्रियाविधि पर प्रकाश डाला गया है।

सांकेतिक शब्द : मायकोस्पोरिन सदृश अमीनों अम्ल, आच्छद वर्णक, साइटोनेमिन यू०वी०–बी विकिरण, आर्द भूमि, सायनोबैक्टीरिया।

Introduction

Ultraviolet (UV) radiation is an important component of solar radiation having a number of deleterious effects on biological systems[1,2]. Based on the wavelength, UV has been arbitrarily sub-divided into UV-A (315 - 400 nm), UV-B (280 - 315 nm) and UV-C (<280 nm). Among different kinds of UV radiations UV-C is strongly mutagenic and lethal whereas UV-A is biologically least reactive component. Ozone present in the stratosphere acts as an efficient screen for short wavelength UV radiation absorbing all UV-C radiation, but allowing all UV-A to reach the earth's surface. On the other hand it allows some UV-B radiation to

reach on to the ground.

Continuing depletion of stratospheric ozone caused by the anthropogenic emission of chlorofluorocarbons and other gaseous pollutants into the atmosphere has resulted in an increase in UV-B radiation[3-5]. Such increases in UV-B radiation are most pronounced in Antarctica, but similar trends have been reported at other latitudes also[6]. It has been estimated that if ozone concentration goes on decreasing, it may encompass a broader range of latitudes in next few decades[7,8]. Besides ozone, to a certain extent, variables such as cloud cover, sun-angle, surface reflectants, aerosols and various tropospheric pollutants also affect the intensity of UV-B radiation reaching the ground thereby leading to a marked latitudinal and seasonal variations in intensity[5].

The continued increase in UV-B radiation has been demonstrated to affect both primary production and higher trophic levels in biological food webs causing instabilities in ecosystems[1,9]. Besides exerting a variety of adverse effects on terrestrial vegetation, UV-B radiation is also known to penetrate fairly deep in freshwater and marine environments[9] where it affects the plankton in the euphotic zone as well as benthic organisms[1]. Cyanobacteria are a large and heterogeneous group of prokaryotic microorganisms which form an important component of the nitrogen-fixing microbial population both in aquatic and terrestrial ecosystems[10]. They are capable of growing in diverse habitats ranging from hot springs to Arctic and Antarctic regions[11] and are the only organisms capable of simultaneously fixing nitrogen and carrying out oxygenic photosynthesis.

The damaging effects of UV-B radiation on cyanobacteria are of special concern because they form a dominant flora of nitrogen-fixing microorganisms in tropical wetland rice paddy fields and enrich the fertility of soil[12]. Any adverse effect on their existence may lead to an imbalance in nitrogen status of entire ecosystem[13]. Besides rice-fields, since most of the habitats occupied by cyanobacteria are directly exposed to sunlight, they are highly vulnerable to the effects of increased solar UV-B radiation. Phylogenetically the group originated during pre Cambrian era before the existence of ozone shield, it is presumed that they faced more intense solar UV-radiation as compared to other organisms. In general they are more tolerant to environmental stresses than are eukaryotic algae, and are believed to have faced a wide spectrum of environmental stresses.

Like other photosynthetic organisms cyanobacteria sense and respond to UV-B radiation although the degree of response significantly varies from species to species. In general the damaging effects of UV-B radiation on cyanobacteria can be classified into two main categories, damage to DNA leading to mutations, and damage to physiological and biochemical processes. Following absorption of UV radiation by DNA formation of a variety of photoproducts may occur. These photoproducts include: cyclobutane-type dimers of thymine, cytosine and uracil, pyrimidine adducts, photohydrates, and DNA- protein cross-links. On the other hand physiological changes seen after increased UV-B radiation exposure may include, growth inhibition followed by loss of survival, inhibition of photosynthetic processes, loss of enzymatic activity, increased synthesis of UV-B absorbing pigments, induction of stress protein, and others[2,14-16]. These changes could result from a number of primary UV-B events such as direct photosynthetic damage, loss of permeability/ membrane changes, pigment destruction, protein/enzyme inactivation, reduced DNA and protein synthesis, reduced uptake of nutrients, hormone inactivation and signal transduction through phycochrome or signal transduction via a specific UV-B photoreceptor[2,17,18]. This article deals with the present status of UV-B-mediated effects on various physiological and biochemical processes in wetland cyanobacteria and the protective mechanisms operative in them to counteract the damaging effects of UV-B radiation.

Effects of UV-B on wetland cyanobacteria

Studies conducted so far reveal that UV-B radiation affects the growth, survival, pigmentation, orientation, general metabolism, photosynthesis, nitrogen fixation and assimilation of nitrogen in diverse cyanobacterial species. There is still considerable discussion about the primary targets of UV-B radiation damage but it is generally felt that the deleterious effects are in part due to the direct effects of UV-B radiation on membrane component[14], DNA[15], enzymes[19], growth regulators and the photosynthetic apparatus, particularly the reaction center of photosystem II and RuBISCO[20,21] or to its indirect effect through the formation of reactive species such as super oxide (O_2^-), hydroxyl radicals (OH^-) or hydrogen peroxide (H_2O_2)[22]. Although DNA has an absorption

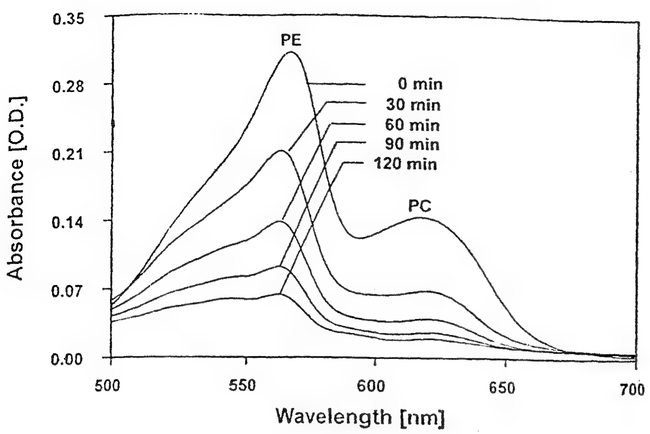


Fig. 1 - Effects of UV-B radiation on pigmentation of the cyanobacterium *Calothrix* sp. PC- phycocyanin and PE-phycoerythrin.

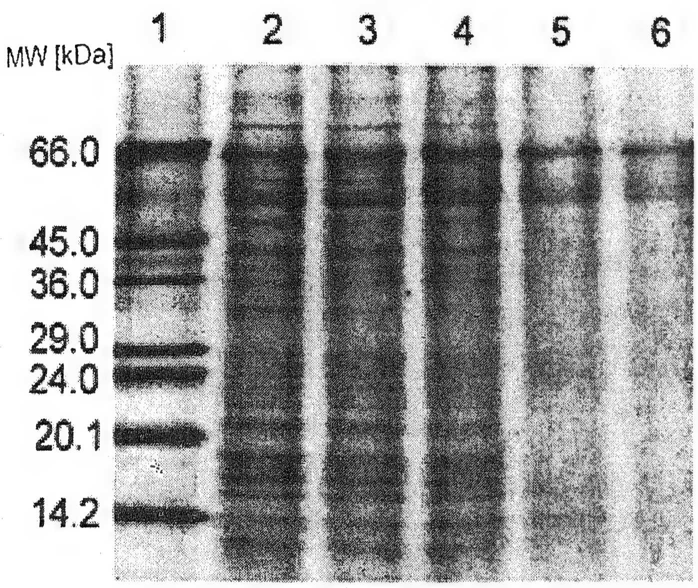


Fig. 2 - Effects of UV-B radiation on total protein profile of the cyanobacterium, *Anabaena* sp. lane 1- marker; lane2- control; lane 3- 30 min; lane 4- 60 min; lane 5- 90 min and lane 6- 120 min of UV-B radiation.

spectrum that peaks at 260 nm, a significant absorption also occurs in the UV-B range (280-315 nm). This results in production of cytotoxic lesions such as pyrimidine base pairs. Such lesions, if left uncorrected, interfere with DNA replication and transcription ultimately leading to mutation or death. Proteins also show considerable absorption in the UV-B region, which is primarily due to the presence of aromatic amino acids such as tryptophan and tyrosine. Such UV-B-induced damage/denaturation of various proteins/enzymes may also cause changes in the structure and function ultimately leading to changes in membrane permeability and functioning of enzymes. Some of the notable effects of UV-B radiation on metabolic processes of cyanobacteria are briefly discussed below :

(i) Motility

Cyanobacteria employ motility and orientation mechanisms to escape harmful UV conditions and high light intensities but it has been reported that these avoidance mechanisms are severely affected by UV-B radiation, resulting in a decrease or loss of their ability to escape from harmful UV conditions[23,24]. Filamentous cyanobacteria such as *Anabaena variabilis, Oscillatoria tenuis* and *Phormidium uncinatum* use gliding motility to optimize their position in their microhabitat. A drastic reduction in the percentage of motile filaments of the above cyanobacteria was recorded within 10-30 min of exposure to unfiltered solar radiation at Ghana[24]. Removal of UV-B radiation by long-pass or band-pass filters resulted in higher percentage of motility in most cases suggesting the inhibitory effect of UV-B radiation on gliding motility of these cyanobacteria. Likewise, inhibition of phototactic orientation and photophobic responses reduce the ability of the organisms to orient themselves in their photo environment. In the event of failure to quickly respond to changes in the photo environment their death may occur[25].

(ii) Cell differentiation

Differentiation of vegetative cells into heterocysts or akinetes is also affected by UV-B radiation[26]. Delayed heterocyst differentiation and akinete formation in *Anabaena aqualis* following exposure to UV-B radiation was noted. It has been suggested that UV-B exposure alters the C:N ratio which in turn affects the spacing pattern of heterocyst in a filament[19]. A decrease in the level of major heterocyst polypeptides (26, 54 and 55 kDa) following UV-B treatment has been recorded which is presumed to be responsible for the disruption of multi-layered heterocyst wall, the essential component for maintaining the active form of nitrogenase. Role of UV-B radiation in the opening of specific calcium channels in the heterocyst of *Anabaena* sp. has also been demonstrated[27]. Whether this opening is mediated through signal transduction pathway and/or has any significance in heterocyst formation and function is yet to be established.

(iii) Survival and growth

UV-B radiation has been shown to severely affect the growth and survival of several wetland cyanobacteria[28-30]. Various species differ with respect to their tolerance to UV-B radiation and even closely related strains show differential sensitivity. Complete killing and loss of survival within 120-180 min of UV-B exposure has been reported for several cyanobacteria[28,29]. Strains such as *Nostoc commune* and *Scytonema* sp. whose filaments are embedded in a mucilage sheath are more tolerant to UV-B radiation than the species which do not have such mucilage covering[19]. In a *Nostoc* strain the phycoerythrin rich (brown) form was found to be more tolerant to UV-B radiation than the phycocyanin rich (blue-green) form of this strain[28]. Two Antarctica cyanobacteria, *Phormidium murrayi* and *Oscillatoria priestleyi*, isolated from a common habitat showed differential sensitivity to UV-B radiation. In contrast to complete suppression of growth in *Oscillatoria priestleyi*, only a 62 % inhibition of growth of *Phormidium murrayi* was observed following exposure to the same quantum of UV-B intensity[30].

(iv) Pigmentation

Several workers have demonstrated that UV-B radiation causes photobleaching of photosynthetic pigments, a decrease in phycocyanin/chlorophyll a ratio and disintegration of phycobilisome complex leading to the release of phycobiliprotein pigment complex[21,25,28,30-33]. Phycobiliprotein seems to be the most sensitive pigment most probably due to its water soluble property. In *vivo* absorption spectra of *O. priesteyi* and *P. murrayi* pigments showed a strong response to UV-B exposure. During a 4 day growth assay, phycocyanin and to a lesser extent Chl *a* dropped with increasing UV-B flux[30]. Sinha *et al.*[21,31] have reported a decrease in the phycobiliprotein content (Fig. 1) and disassembly of phycobilisomal complex following UV-B irradiation in a number of cyanobacteria. The pattern of fluorescence emission spectra of phycobiliproteins observed after UV-B irradiation suggests an impairment of energy transfer from the accessory pigments to the photosynthetic reaction centers[21,31]. Exposure of cyanobacterial cultures to intense UV-B radiation causes bleaching of phycocyanin and phycoerythrin which is in accordance with the disintegration of phycobilisomes[33].

(v) Photosynthesis

Photosynthetic parameters such as $^{14}CO_2$ uptake, O_2 evolution and ribulose-1,5 bisphosphate carboxylase (RuBISCO) activity are greatly inhibited following exposure to UV-B radiation[20,21,30]. Photosynthetic O_2 evolution of a *Phormidium* strain from Lake Baikal declined within minutes of exposure to solar irradiation[25]. Several workers have reported an inhibition of $^{14}CO_2$ uptake in a number of cyanobacteria following exposure to UV-B irradiation[19,28,34]. In a study of diurnal variability of the effect of solar UV-radiation on photosynthesis in an algal mat comprising of *Lyngbya aestuarii*, Cockell and Rothschild[35] found a mean increase in the total primary productivity (measured in terms of $^{14}CO_2$ uptake) over the day when solar UV-B was screened out. It is felt that RuBISCO may undergo a number of modifications such as photodegradation, fragmentation and denaturation of polypeptide chain, change in active site and increased solubility of membrane proteins[13]. In addition supply of ATP and $NADPH_2$ may also be inhibited which may cause inhibition of CO_2-fixing ability. The D_1 and D_2 polypeptides which are the major constituents of PS-II reaction centers are also degraded, even after exposure to intermediate levels of UV-B radiation[36,37]. UV-B radiation may also induce modifications and photodegradation of membrane proteins, which may subsequently affect the integrity of thylakoid membrane thereby causing the damage of photosynthetic components which are otherwise essential for active CO^2 fixation.

(vi) Nitrogen metabolism

Among all the key enzymes involved in nitrogen metabolism, the nitrogen-fixing enzyme nitrogenase has been found to be extremely sensitive to UV-B radiation[18,28,33,38]. In a *Nostoc* sp., nitrogenase activity was lost within 45 min of UV-B exposure whereas nitrate reductase and glutamine synthetase activity remained more or less unaffected[28]. Complete inactivation of nitrogenase activity within 25 - 40 min of UV-B exposure has been reported in a number of cyanobacteria including *Anabaena* sp., *Nostoc* sp., *Calothrix* sp. and *Scytonema* sp[18]. Employing inhibitors of protein synthesis and PS-II activity they have demonstrated that restoration of nitrogenase activity in UV-B-treated cultures occurs only after fresh synthesis of nitrogenase polypeptide. The inactivation of activity most probably occurs due to complete damage

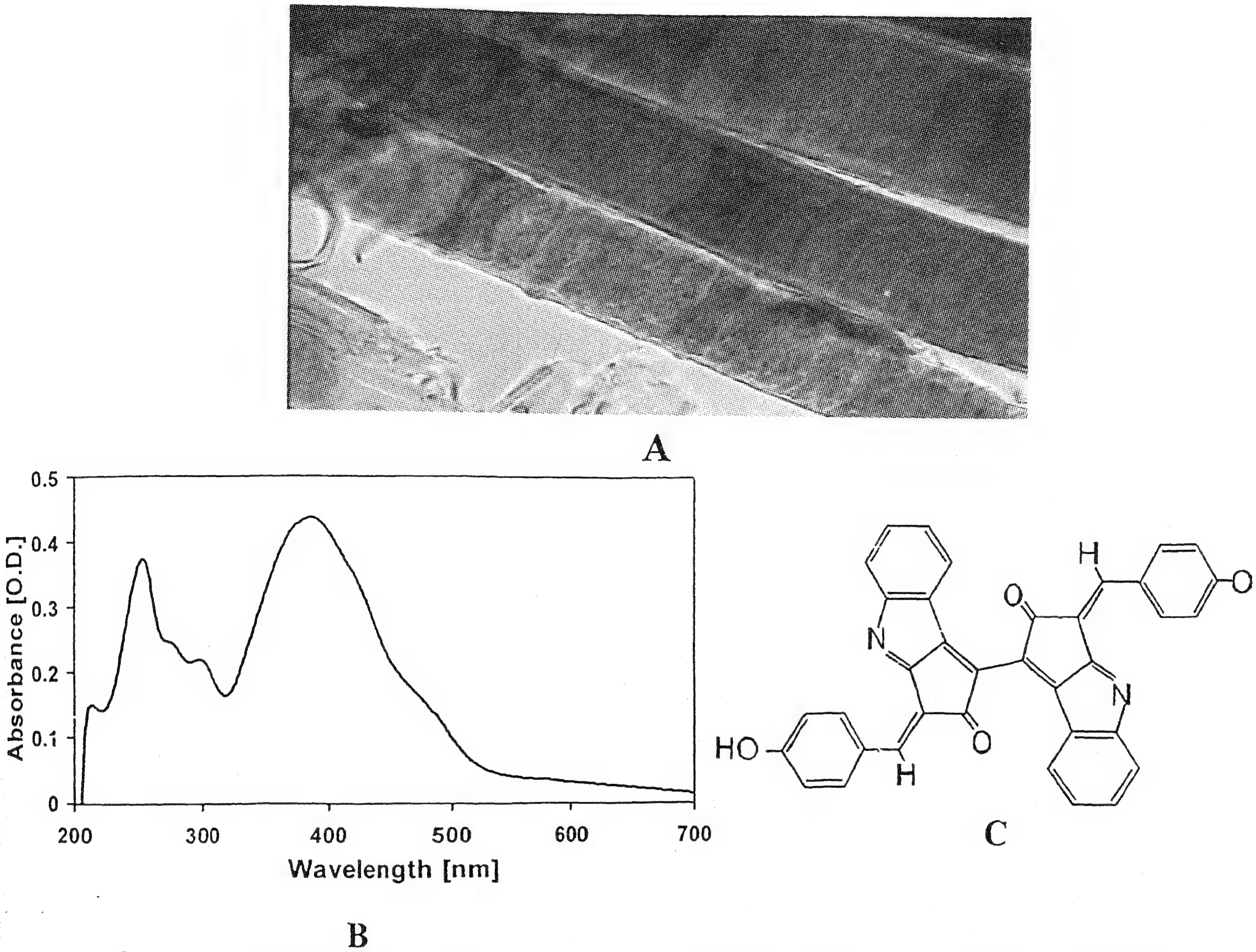


Fig. 3 - Photograph showing the presence of yellow-brown photoprotective pigment, (A) scytonemin in the sheath of the cyanobacterium *Lyngbya* sp., (B) Absorption spectrum and (C) molecular structure of the scytonemin.

to the nitrogenase polypeptide. It has been suggested that the aromatic amino acids present or the native structure of nitrogenase is responsible for the extremely susceptible nature of nitrogenase to UV-B radiation.

(vii) Protein profile

Exposure to UV-B radiation is known to causes a subtle change in the protein profile of several cyanobacteria[14,31]. Increased duration of UV-B radiation exposure brings about a linear decrease in the number and quantity of protein bands of a number of cyanobacteria[21]. In case of a *Nostoc* sp., the low molecular weight proteins of around 20 kDa ($\alpha\beta$ monomers of phycocyanin) were the most affected one. It is interesting to find that UV-B radiation has a drastic effect specifically on low molecular weight proteins. In a comparative study on the effects of UV-B treatment on total protein profile of several cyanobacteria, Sinha *et al.*[29,31], reported complete loss of protein bands between 14.5 and 45 kDa after 90 and 120 min of UV-B exposure in *Nostoc carmium* and *Anabaena* sp. (Fig. 2). However protein bands of relatively higher molecular weight viz., 55 and 66 kDa were unaffected even after 120 min of UV-B exposure. In species such as *N. commune* and *Scytonema* sp. which contain a mucilage covering/sheath, complete elimination of bands occurred only after 150 min of UV-B exposure[29,31]. The increased tolerance to UV-B radiation in certain species may be ascribed to the presence of mucilage covering or photoprotectants such as scytonemin and mycosporine-like amino acids (MAAs) in the cell.

(viii) DNA damage

Although DNA has an absorption spectrum that peaks at 260 nm, but a significant absorption also occurs between 280 - 315 nm. A variety of lesions in DNA after UV-B radiation have been identified. These lesions result either due to direct absorption of UV-B radiation by DNA or from free radicals and reactive oxygen species formed by various photochemical processes. The main class of UV-induced lesions consist of dimeric photoproducts such as cis-syn cyclobutane pyrimidine dimers (CPDs) and pyrimidine (6-4) pyrimidone photoproducts (6-4 PPs)[15,39]. Photoproducts formation interferes with DNA synthesis and RNA transcription, ultimately leading to mutation or death of the organism.

The damaging effects of UV-B radiation on DNA and formation of various photoproducts are well known in a number of organisms including the Antarctic marine planktonic diatom communities[40,41]. However little information is available regarding the specific effects of UV-B radiation on DNA of cyanobacteria, although few studies have been conducted with UV-C radiation[42,43]. Sinha *et al.*[16] have demonstrated that exposure to UV-B radiation could induce the formation of thymine dimers in three rice-field cyanobacteria, *Nostoc, Anabaena* and *Scytonema* sp. The frequency of dimer formation increased with increase in exposure time and a 120 min exposure of these cyanobacteria to UV-B radiation led to dimer frequency of 35 - 40 %. By using blotting and chemiluminescence method these workers successfully developed a relatively quick, simple and efficient method for the quantitative analysis of thymine dimers in aquatic primary producers including cyanobacteria[16]. Recently UV-B induced formation of CPD has also been reported in bacterioplankton[44].

UV-ABSORBING/SCREENING MECHANISMS

Since cyanobacteria are believed to have originated in the Precambrian era at a time when ozone shield was absent[45], they presumably faced high fluxes of UV radiation which must have acted as an evolutionary pressure leading to selection for efficient UV radiation protecting mechanisms. Tolerance of cyanobacteria to intense sunlight as well as UV radiation might have contributed to their success during early stages of colonization. As a consequence they have developed effective mechanisms to counteract the damaging effects of UV-B radiation. In case of microbes behavioral responses as well as external and internal mechanisms of protection against UV-induced damages have been reported and it has been proposed that several of these mechanisms for UV-protection and/or repair of UV-induced damage might have worked singly or in various combinations[46]. These defense strategies include the avoidance of brightly lit habitats, UV-screening by cellular and extracellular photoprotectants, quenching reaction for phototoxic products and the efficient repair mechanisms which include DNA photorepair, light independent nucleotide excision repair and the UV-A/blue light-mediated repair of photosynthetic apparatus[47,48]. A number of UV-absorbing/screening strategies operating in cyanobacteria are summarized below:

(i) Avoidance

Motile organisms use very precise orientation mechanisms to adjust their position within the water column in response to signals like light, gravity, chemical and temperature gradients and magnetic field of the earth. Motility and orientation strategies such as negative phototaxis, photokinetic and photophobic reactions and movements up and down in a water column or formation of microbial mat are useful mechanisms to counteract the adverse impact of UV-B radiation[24,25]. Gliding ability of Oscillatorean trichomes in microbial mat and optimization of vertical movement of bloom- forming cyanobacteria in a water column by gas vasicles[49] are key strategies which protect cyanobacteria against UV-B radiation. As such the sinking and floating behaviour by a combination of gas vacuole and ballast act as an important means of protection against UV-B damage in a number of cyanobacteria. In Antarctica many cyanobacterial species form thick mucilage mats where the deep strata containing much of the biomass are completely screened from UV as well as short photosynthetically active radiation (PAR)[47]. Cyanobacterial populations form crusts, films and massive mats attaining up to several centimeters in thickness and more frequently associated with deep pigmentation. Such morphological adaptations allow cyanobacteria to thrive and tolerate high PAR as well as elevated level of UV-B intensity. The motile trichomes of *O. priestleyi* remain well below the microbial mat surface during the continuous daylight of Antarctica summer and rise to the surface only after prolonged period of shading[30]. Photosynthetic microbial blankets are commonly formed in environments where solar UV is a significant stress[50]. These benthic com-

munities are rich in cyanobacteria and develop commonly in tropical and subtropical shallow water bodies or wetlands. Within the microbial blankets, individuals of cyanobacteria optimize their position by some sorts of vertical movement which seems to be induced and regulated by both visible and UV-B radiation[50]. Exposure to moderate doses of UV-B radiation to surface layers of microbial mats, dominated by *Microcoleus chthonoplastes*, from a salt lake in Egypt caused migration in response to added UV-B radiation[50]. One of the survival strategies, reported by Blakefield and Harris (1994)[26] is the increase in total number of akinetes produced, besides some delay in heterocyst production and akinete formation in certain species of cyanobacteria. Under such conditions the increased number of akinetes enhances the chance of survival.

(ii) Quenching

The interaction of UV-radiation with oxygen and organic compounds can produce highly reactive toxic intermediates such as super oxide (O_2^-), hydroxyl radicals (OH^-) or hydrogen peroxide. In cyanobacteria there are two quenching mechanisms (a) possession of high concentration of carotenoids and, (b) existence of enzymatic defenses against super oxides and related oxidants, that allow them to detoxify the highly reactive photochemical reactive products[47,51].

Carotenoids are photosynthetic accessory pigments having a number of physiological roles. Besides acting as a light harvesting pigment they can also neutralize singlet state oxygen and also participate in xanthophyll cycle which consists of a set of reactions that dissipate excess solar energy. In some Antarctican benthic mats of cyanobacteria consisting of *Nostoc commune* and *Oscillatorea* sp. the surface layers contain high amounts of carotenoids such as myxoxanthophyll and canaxanthin, which give bright orange or pink colouration and act as photoprotectants[47]. Liquid cultures of the terrestrial cyanobacterium, *Nostoc commune* derived from field material showed an increase in carotenoids especially echinenone and myxoxanthophylls following a 5 h exposure to UV-B radiation[52]. The total carotenoid to chlorophyll ratio after one day of UV-B irradiation was found to be 34-40% higher than that in the untreated control. The presence of echinenone and myxoxanthophylls has also been demonstrated in the outer membrane of *Synechocystis* sp[53]. It has been proposed that myxoxanthophyll and echinenone are outer membrane bound UV-B photoprotectants of *Nostoc commune* whose induction by UV-B radiation is a fast active SOS response whereas other UV- screening pigments are passive UV-screens produced against long-time exposure to UV-B radiation[52].

Many species of cyanobacteria are known to possess superoxide dismutase which scavanges superoxide radicals and convert it to hydrogen peroxide. The hydrogen peroxide so produced is then converted to water and O_2 via a combined catalase-peroxidase system[54]. Since many of the effects of UV-B radiation are mediated by reactive oxygen species, these enzymatic defense strategies may have a role as protectant against UV-B radiation. Irradiation of *Anacystis nidulans* culture with near UV radiation (295 - 390 nm) has been shown to induce shock proteins which may include superoxide dismutase and related proteins[55]. However the distribution of such enzymatic defense system in various cyanobacteria and their relationship with UV-B conditions has not yet been explored[17,56].

(iii) Screening

An important mechanism to prevent UV-induced photodamage, is the synthesis of UV-absorbing compounds. Phenylpropanoids, mainly flavonoid derivatives and melanins are known to protect higher plants and animals, respectively, from harmful UV radiation. In cyanobacteria photoprotectants such as scytonemin and mycosporine-like amino acids (MAAs), having strong absorption in the UV-A and/or UV-B region of the spectrum play an important role in allowing these organisms to grow and survive in habitats exposed to strong irradiation. In the terrestrial *Nostoc commune* strain, subjected to regular cycles of desiccation and rewetting, UV-absorbing compounds play a key role as UV-protectants[52]. Role of various screening compounds in UV-B protection is discussed below:

(a) Scytonemin

Scytonemin is a yellow-brown colored pigment occurring in the extracellular sheath of a number of terrestrial cyanobacteria (Fig. 3A) especially in those species growing in habitats exposed to intense solar radiation[57,58]. It is a lipid soluble compound having *in vivo* absorption maximum at 370 nm in the UV-A region but shows considerable absorption in the UV-B region also. Purified scytonemin shows absorption maximum at 386 nm although there being appreciable absorbance at 252, 278 and 300 nm (Fig. 3B). It is a novel dimeric pigment composed of indole

and phenolic subunits (Fig. 3C) with a molecular mass of 544 Da[59]. Microspectrophotometric measurements of the transmittance of pigmented sheath and the quenching of ultraviolet excitation of phycocyanin fluorescence suggest that the pigment is effective in shielding the cells from incoming UV radiation and is able to reduce the incident UV-A radiation entering the cells to around 90%[57,60,61].

In *Chlorogloeopsis* and *Diplococcon* the rate of synthesis of scytonemin could be induced by exposure to UV-A or blue light and physiological removal of the scytonemin containing envelope resulted in a loss of resistance to photobleaching by UV-A radiation[60]. In a natural population of *Calothrix* sp. receiving solar irradiance, high scytonemin content is required for uninhibited photosynthesis under high UV-B flux[61]. Scytonemin may constitute as much as 5 % of total cellular dry weight or even higher in some naturally occurring cyanobacteria[62]. Since rapid photodegradation of scytonemin does not occur, it is highly stable and able to persist very long in terrestrial cyanobacterial crusts or dried mats[60,61,63-65]. This property may be helpful for cyanobacteria which face intermittent periods of physiological activity such as desiccation and freezing. It has been proposed that appearance of scytonemin during the Precambrian era must have helped the cyanobacteria in the colonization of exposed, shallow water and terrestrial habitats[63]. Recently, Fleming and Castenholz[66] have shown that when the cells were hydrated for two days in between desiccation periods had high scytonemin synthesis compared to the cells which were hydrated for one day in *Nostoc punctiforme*, but in *Chroococcidiopsis* periodic desiccation inhibits scytonemin synthesis. Besides having a role as UV protectant, scytonemin may have additional roles such as protection against pathogenic attack, bacterial decomposition or herbivore grazing[14].

(b) Mycosporine-like amino acids (MAAs)

The other class of photoprotectants is colorless, water soluble MAAs having absorption maxima in the UV range between 310 - 362 nm. First identified in fungi, these compounds are now reported to be present in a number of taxonomically diverse groups of organisms from eukaryotic and prokaryotic classes. They are present in cyanobacteria[67-70], eukaryotic algae[71,72], marine heterotrophic bacteria and marine invertebrates[72], fish[73] and in a wide variety of other marine organisms[72,74-76]. Among cyanobacteria, MAAs have been reported from species growing in freshwater, marine or terrestrial habitats[58,67,68,77]. Their presence has also been reported from strains growing in Antarctica[30] as well as from a community of halophilic species[78].

Structurally these compounds contain cyclohexenone or cyclohexenime chromophore conjugated with the nitrogen substituent of an amino acid or its imino alcohol and have an average molecular weight of 300[68,77,79]. In a survey of 20 strains of cyanobacteria (belonging to 13 genera) isolated from exposed habitats, Garcia-Pichel and Castenholz[58] demonstrated the presence of MAAs in 13 strains. In all 13 distinct compounds were found in these strains. The specific MAA content in these isolates was found to vary between 0.16 to 0.84% of the total dry weight. In a terrestrial *Gloeocapsa* strain, the intracellular concentration of MAA was found directly related to the intensity of the UV-B radiation received by the cells[67]. Moreover high content of MAA inside the cells conferred increased resistance to UV-B radiation. Sinha *et al.*[70] have demonstrated the induction of MAAs by solar ultraviolet-B radiation in three cyanobacteria namely, *Anabaena* sp., *Scytonema* sp. and *Nostoc commune*. They reported that PAR and UV-A were ineffective in causing induction of MAAs. All these cyanobacteria possessed only a single type of MAA which was identified as shinorine. Shinorine is a bisubstituted MAA containing both glycine and serine groups with absorption maximum at 334 nm.

The presence of MAAs in cyanobacteria is restricted not only to non-planktonic species rather typical MAA-like absorbance bands in field samples of planktonic cyanobacteria such as *Gloeotrichea, Aphanizomenon* and *Microcystis* sp. have also been demonstrated[67]. Field populations of halotolerant cyanobacteria are also known to possess high concentrations of MAAs[78]. It has been suggested that the content of MAAs in the cell is regulated by osmotic mechanisms[78]. The conclusive evidence for the exclusive role of MAAs as a sunscreen pigment is lacking and hence forth it has been speculated that besides acting as sunscreens; they may transfer energy to the photosynthetic reaction centers[69,80], may have a role in osmotic regulation[78,81] and, they may act as antioxidants and prevent cellular damage resulting from UV-induced production of highly reactive oxygen species[74]. Interestingly, in laboratory-grown cultures

of *Chlorogloeopsis* sp., both UV and osmotic stress are able to induce and regulate the synthesis of MAAs[82,83]. In this species, a specific UV-B photoreceptor, probably pterin, may mediate MAA induction[83]. However, in *Anabaena* sp. and *Nostoc commune* the induction of MAAs (identified as shinorine) was found to be solely under photocontrol and occurs only by UV radiation and PAR does not seem to be effective in induction of MAAs[84,85].

A terrestrial species of *Nostoc commune* when exposed to high solar radiation was found to possess a UV-A/B absorbing pigment with absorption maxima at 312 and 325 nm[86]. In this species, an oligosaccharide MAA (OS-MAA), has been shown to be located in the extracellular glycan sheath[52,87]. It is the first mycosporine so far known to be covalently linked to the oligosaccharide and located outside the cell[87]. Sinha *et al.*[88] have shown the UV-B induced synthesis of two MAAs such as shinorine and porphyra-334 in three strains of *Nodularia*. This substance besides providing protection by absorbing UV radiation may also provide additional protection by quenching[74].

Besides scytonemin and MAAs, occurrence of a few other UV-absorbing compounds, conferring resistance to UV radiation to the organisms, have been reported[89]. The shielding role of a brown-coloured pigment (having major absorption peak at 314 nm) from *Scytonema hofmanii* and a phycoerythrin rich pink extract from *Nostoc spongiaeforme*, against UV-B-induced damage, has been reported[89]. A strain of *Nostoc* sp. showing resistance to high light intensity and UV radiation has been reported to produce three different UV-absorbing compounds having absorption maxima at 256, 314 and 400 nm[90].

During the last few decades vast information on UV-B absorbing/screening substances from diverse organisms have been gathered and this has led to the development of a database on photoprotective compounds in various organisms[77]. Readers may find detailed information on the web site (http://www.biologie.uni-erlangen.de/botanik1/html/eng/maa_database.htm).

(iv) Repair

The damaging effects of UV-B radiation can be alleviated by UV-A or visible radiation[63] suggesting that in nature severity of the damaging effects of UV-B can be reduced by PAR and UV-A present in the solar radiation. The existence of efficient mechanisms to repair the UV-induced lesions is well known in a variety of organisms, including cyanobacteria[39,62,63,70,91]. Basically there are three known mechanisms that can repair the UV-induced DNA lesions. These are photoreactivation which consists of enzymatic monomerization of UV-induced dimers brought about by visible/UV-A radiation through the activity of photolyase[92], the dark or excision repair and the recombinational repair[16]. Photorepair of UV-C-induced DNA damage is well known in several cyanobacteria[42,93] and the photolyase has been purified from *Anacystis nidulans*[43,94]. The action spectra for photoreactivation of UV-C-induced DNA damage in different species of cyanobacteria show that UV-A and blue-light are most effective. Similar kind of studies involving repair of UV-B-induced DNA damage in cyanobacteria is lacking although Karentz *et al.*[40] have studied the cellular and molecular aspects of UV-B-induced DNA damage and its repair in Antarctic diatom communities. Buma *et al.*[41] have also reported UV-B-induced thymine-dimer formation and its repair in a marine diatom *Cyclostella* sp.

Han *et al.*[48] have reported photoreactivation of UV-B-induced inhibition of photosynthesis in *Anabaena* sp. The action spectrum for photoreactivation showed major peaks at 352.5 and 383 nm along with an additional peak at 411 nm suggesting that both UV-A and blue-light are effective in photoreactivation in this species. The unusually large number of DNA copies in cyanobacteria may confer an additional protection against long-term UV-B damage. The existence of polyploidy in cyanobacteria may be of additional importance since this may mask the effect of single mutations of a DNA molecule.

Conclusions

Increased intensity of UV-B radiation has now been unequivocally demonstrated to show detrimental effect on a number of vital physiological and biochemical processes of cyanobacteria. Such effects lead to reduced growth and survival. UV-B affects pigmentation, disintegrates phycobilisomes, severely inhibits photosynthetic processes and causes inactivation of nitrogenase. Major alterations in general protein profile of a number of cyanobacteria have also been reported. Formation of dimers between two adjacent pyrimidine bases, *cis*-syn cyclobutane dimers and pyrimidine (6-4) pyrimidone products following UV-B exposure in certain cyanobacteria has also been

demonstrated. Unfortunately most of the studies pertaining to UV-B radiation effects on cyanobacteria are based on short term laboratory experiments employing high UV-B flux. Only a few short-term experiments that utilize solar UV-B radiation obtained by using various long-pass filters are available[24]. Conclusions about the long-term ecological impacts of ambient natural UV-B radiation cannot be accurately forecasted from results obtained through short-term incubation studies.

Since in nature, organisms are seldom affected by only a single stress factor, it is worth to consider that the effectiveness of UV-B radiation can be greatly modified by a number of other factors such as water-stress, increase in atmospheric CO_2, global mean temperature and presence of heavy metals like cadmium, mercury, copper, lead and nickel. Hence other environmental and biological variables should also be taken into account while attempting a realistic assessment of the effects of enhanced levels of UV-B radiation. The existence of various protective/repair strategies provide a high level of natural defense against the potential effects of elevated UV-B radiation. Information related to the ecological significance of sunscreening substances such as scytonemin and MAAs and spatial distribution of MAAs within the cyanobacterial cells is still in infancy stage. Since UV-B damage is ameliorated by PAR and UV-A, UV-B/UV-A ratio has a major influence on the extent of UV-B damage. The existence and significance of emzymatic defense mechanisms and repair of UV-B-induced DNA damage in cyanobacterial populations deserve critical study. Because of differential sensitivity of organisms to UV-B radiation, changes in species composition are bound to occur which might affect biological diversity. Although during the last few decades vast knowledge covering diverse aspects of UV-B effects on living organisms have accumulated but there are still a number of gaps left in for clear understanding which need careful attention.

References

1. Häder D-P, Kumar HD, Smith RC, Worrest RC. Effects of solar UV radiation on aquatic ecosystems and interactions with climate change. *Photochem Photobiol Sci* 2007; 6 : 267-285.
2. Xue L, Zhang Y, Zhang T, An L, Wang X. Effects of enhanced ultraviolet-B radiation on algae and cyanobacteria. *Crit Rev Microbiol* 2005; **31** : 79-89.
3. Crutzen PJ. Ultraviolet on the increase. *Nature* 1992; **356**: 104-105.
4. Molina MJ, Molina LT. Stratospheric ozone. In: Dunnette D, O'Brien RJ, editors. The Science of Global Change. The Impact of Human Activities on the Environment. Washington DC: American Chemical Society, 1992. pp. 24-35.
5. Madronich S, McKenzie RL, Björn LO, Caldwell MM. Changes in biologically active ultraviolet radiation reaching the Earth's surface. *J Photochem Photobiol B: Biol* 1998; **46** : 5-19.
6. Kerr JB, Mcelroy CT. Evidence for large upward trends of ultraviolet-B radiation linked to ozone depletion. *Science* 1993; **262** : 1032-1034.
7. Vonder Gathen P, Rex M, Harris NRP, Lucic D, Knudsen BM, Braathen GO, De Backer H, Fabian R, Fast H, Gil M, Kyrö E, Mikkelsen IS, Rummukainen M, Stähelin J, Varotsos C. Observational evidence for chemical ozone depletion over the Arctic in winter 1991-1992, *Nature* 1995; **375** : 131-134.
8. Weatherhead EC, Andersen SB. The search for signs of recovery of the ozone layer. *Nature* 2006; **441** : 39-45.
9. Smith RC, Prezelin BB, Baker KS, Bidigare RR, Boucher NP, Coley T, Karentz D, MacIntyre S, Matlick HA, Menzies D, Ondrusek M, Wan Z, Waters KJ. Ozone depletion: ultraviolet radiation and phytoplankton biology in Antarctic waters. *Science* 1992; **255** : 952-959.
10. Stewart WDP. Some aspects of structure and function in N2-fixing cyanobacteria. *Annu Rev Microbiol* 1980; **34**: 497-536.
11. Stanier RY, Cohen-Bazire G. Phototrophic prokryotes: the cyanobacteria. *Ann Rev Microbiol* 1977; **31** : 225-274.
12. Singh RN. Role of blue-algae in nitrogen economy of Indian agriculture, New Delhi: Indian Council of Agricultural Research, 1961.
13. Sinha RP, Häder D-P. Effects of ultraviolet-B radiation in three rice field cyanobacteria. *J Plant Physiol* 1998; **153**: 763-769.
14. Sinha RP, Häder D-P. Life under solar UV radiation in aquatic organisms. *Adv Space Res* 2002; **30** : 1547-1556.
15. Häder D-P, Sinha RP. Solar ultraviolet radiation-induced DNA damage in aquatic organisms: potential environmental impact. *Mut Res* 2005; **571** : 221-233.
16. Sinha RP, Dautz M, Häder D-P. A simple and efficient method for the quantitative analysis of thymine dimers in cyanobacteria, phytoplankton and macroalgae. *Acta Protozool* 2001; **40** : 187-195.
17. Vincent WF, Roy S. Solar ultraviolet-B radiation and aquatic primary production: damage, protection and recovery. *Env Rev* 1993; **1** : 1-12.

18. Kumar A, Tyagi MB, Jha PN, Srinivas G, Singh A. Inactivation of cyanobacterial nitrogenase after exposure to ultraviolet-B radiation. *Curr Microbiol* 2003; **46** : 380-384.

19 Sinha RP, Singh N, Kumar A, Kumar HD, Häder M, Häder D-P. Effect of UV radiation on certain physiological and biochemical processes in cyanobacteria. *J Photochem Photobiol B: Biol* 1996; **32** : 107-113.

20. Wilson MI, Ghosh S, Gerhardt KE, Holland N, Sudhakar Babu T, Edeeman M, Dumbroff EB, Greenberg BM. *In vivo* photomodification of ribulose-1,5-bisphosphate carboxylase/oxygenase holoenzyme by ultraviolet-B radiation *Plant Physiol* 1995; **109** : 221-229.

21 Sinha RP, Singh N, Kumar A, Kumar HD, Häder D-P. Impacts of ultraviolet-B irradiation on nitrogen-fixing cyanobacteria of rice paddy fields. *J Plant Physiol* 1997; **150** : 188-193.

22. He YY, Häder D-P. Involvement of reactive oxygen species in the UV-B damage of the cyanobacterium, *Anabaena* sp. *Photochem Photobiol* 2002; **66** : 73-80.

23. Donkor VA, Häder D-P. Effects of solar and ultraviolet radiation on motility, photomovement and pigmentation in filamentous, gliding cyanobacteria. *FEMS Microbiol Ecol* 1991; **86** : 159-168.

24. Donkor VA, Damian HAK, Häder D-P. Effects of tropical solar radiation on the motility of filamentous cyanobacteria. *FEMS Microbiol Ecol* 1993; **12** : 143-148.

25 Häder D-P, Worrest RC. Effects of enhanced solar radiation on aquatic ecosystems. *Photochem Photobiol* 1991; **53** : 717-725.

26. Blakefield MK, Harris DO Delay of cell differentiation in *Anabaena aequalis* caused by UV-B radiation and the role of photoreactivation and excision repair. *Photochem Photobiol* 1994; **59** . 204-208

27. Richter P, Krywult M, Sinha RP, Häder D-P. Calcium signals from heterocysts of *Anabaena* sp. after UV irradiation. *J Plant Physiol* 1999; **154** : 137-139.

28. Tyagi R, Srinivas G, Vyas D, Kumar A, Kumar HD. Differential effect of ultraviolet-B radiation on certain metabolic processes in a chromatically adapting *Nostoc*. *Photochem Photobiol* 1992; **55** : 401-407.

29. Sinha RP, Kumar HD, Kumar A, Häder D-P. Effects of UV-B irradiation on growth, survival, pigmentation and nitrogen metabolism enzymes in cyanobacteria. *Acta Protozool* 1995; **34** : 187-192.

30. Quesada A, Vincent WF. Strategies of adaptation by antarctic cyanobacteria to ultraviolet radiation. *Eur J Phycol* 1997; **32** : 335-342.

31. Sinha RP, Lebert M, Kumar A, Kumar HD, Häder D-P. Disintegration of phycobilisomes in a rice field cyanobacterium *Nostoc* sp. following UV irradiation. *Biochem Mol Biol Intern* 1995; **37** : 697-706.

32. Six C, Joubin L, Partensky F, Holtzendorff J, Garczarek L. UV-induced phycobilisome dismantling in the marine picocyanobacterium *Synechococcus* sp. WH8102. *Photosynth Res* 2007; **92** : 75-86.

33. Sinha RP, Kumar A, Tyagi MB Häder D-P. Ultraviolet-B-induced destruction of phycobiliproteins in cyanobacteria. *Physiol Mol Biol Plants* 2005; **11** : 313-319.

34. Newton JW, Tyler DD, Slodki ME. Effect of ultraviolet-B (280-320 nm) radiation on blue-green algae (cyanobacteria): possible biological indicators of stratospheric ozone depletion. *Appl Environ Microbiol* 1979; **37** : 1137-1141.

35. Cockell CS, Rothschild LJ. The effects of UV radiation A and B on diurnal variation in photosynthesis in three taxonomically and ecologically diverse microbial mats. *Photochem Photobiol* 1999; **69** : 203-210.

36. Sass L, Spetea C, Mate Z, Nagy F, Vass I. Repair of UV-B induced damage of photosystem II via de novo synthesis of the D1 and D2 reaction centre subunits in *Synechocystis* sp. PCC6803. *Photosynth Res* 1997; **54** : 55-62.

37. Campbell D, Eriksson MJ, Öquist G, Gustafsson P, Clarke AK. The cyanobacterium *Synechococcus* resists UV-B by exchanging photosystem II reaction-centre D1 proteins. *Proc Natl Acad Sci (USA)* 1998; **95** : 364-369.

38. Kumar A, Sinha RP, Häder D-P. Effect of UV-B on enzymes of nitrogen metabolism in the cyanobacterium *Nostoc* sp *J Plant Physiol* 1996; **148** · 86-91.

39. Sinha RP, Häder D-P. UV-induced DNA damage and repair: a review. *Photochem Photobiol Sci* 2002; **1** : 225-236.

40 Karentz D, Cleaver JE, Mitchell DL. Cell survival characteristics and molecular responses of Antarctic phytoplankton to ultraviolet-B radiation. *J Phycol* 1991; **27** : 326-341.

41. Buma AGJ, Van Hannen EJ, Roza L, Veldhuis MJW, Gieskes WWC. Monitoring ultraviolet-B induced DNA damage in individual diatom cells by immunofluorescent thymine dimer detection. *J Phycol* 1995; **51** : 314-321.

42. Levine E, Thiel T. UV-inducible DNA repair in the cyanobacteria *Anabaena* sp. *J Bacteriol* 1987; **169** : 3988-3993.

43. Eker AP, Kooiman P, Hessels JKC, Yasui A. DNA photoreactivating enzyme from the cyanobacterium *Anacystis nidulans*. *J Biol Chem* 1990; **14** : 8009-8015.

44. Hernández KL, Renato A. Quiñones RA, Daneri G, Farias ME, Helbling EW. Solar UV radiation modulates daily production and DNA damage of marine bacterioplankton from a productive upwelling zone (36°S), Chile. *J Experim Mar Biol Ecol* 2007; **343** : 82-95.

45. Schopf JW. The oldest fossils and what they mean. In: Schopf JW, editor. Major Events in the History of Life. Boston : Jones and Bartlett Publishers, 1992. pp. 29-64.

46. Pierson BK, Mitchell HK, Ruff-Roberts AL. *Chloroflexus aurantiacus* and ultraviolet radiation: implications for archean shallow water stromatolites. *Ori Life Evol Biosph* 1993; **23** : 243-260.

47. Vincent WF, Quesada A. Ultraviolet radiation effects on cyanobacteria: implications for Antarctic microbial ecosystems. In: Weiler CS, Penhale PA, editors. Ultraviolet Radiation in Antarctica: Measurements and Biological Effects. Antarctic Research Series Vol. 02, Washington DC: American Geophysical Union, 1994. pp. 111-124.

48. Han T, Sinha RP, Häder D-P. UV-A/blue light-induced reactivation of photosynthesis in UV-B irradiated cyanobacterium, *Anabaena* sp. *J Plant Physiol* 2001; **158**: 1403-1413.

49. Reynolds CS, Oliver RL, Walsby AE. Cyanobacterial dominance: the role of buoyancy regulation in dynamic lake environments. *Newzealand J Mar Freshwater Res* 1987; **21** : 379-390.

50. Bebout BM, Garcia-Pichel F. UV-B induced vertical migrations of cyanobacteria in a microbial mat. *Appl Environ Microbiol* 1995; **61** : 4215-4222.

51. Karsten U, Garcia-Pichel F. Carotenoids and mycosporine-like amino acid compounds in members of the genus *Microcoleus* (Cyanobacteria): a chemosystematic study. *System Appl Microbiol* 1996; **19** : 285-294.

52. Ehling-Schulz M, Bilger W, Scherer S. UV-B-induced synthesis of photoprotective pigments and extracellular polysaccharides in the terrestrial cyanobacterium *Nostoc commune*. *J Bacteriol* 1997; **179** : 1940-1945.

53 Jürgens UJ, Weckesser J. Carotenoid-containing outer membrane of *Synechocystis* sp. strain PCC6714. *J Bacteriol* 1985; **164** : 384-389.

54. Tel-Or E, Huflejt ME, Packer L. Hydrogen peroxide metabolism in cyanobacteria. *Arch Biochem Biophy* 1986; **246** : 396-402.

55. Shibata H, Baba K, Ochiai H. Near UV irradiation induces shock proteins in *Anacystis nidulans* R-2; possible role of oxygen. *Plant Cell Physiol* 1991; **32** : 771-776.

56. Canini A, Grilli Caiola M, Civitareale P, Galiazzo F. Superoxide dismutase in symbiotic, free-living and wild *Anabaena* and *Nostoc* (Nostocales, Cyanophyta). *Phycologia* 1992; **31** : 225-230.

57. Garcia-Pichel F, Castenholz RW. Characterization and biological implications of scytonemin, a cyanobacterial sheath pigment. *J Phycol* 1991; **27** : 395-409.

58. Garcia-Pichel F, Castenholz RW. Occurrence of UV-absorbing mycosporine-like compounds among cyanobacterial isolates and an estimation of their screening capacity. *Appl Environ Microbiol* 1993; **59** : 163-169.

59. Proteau PJ, Gerwick WH, Garcia-Pichel F, Castenholz RW. The structure of scytonemin, an ultraviolet sunscreen pigments from the sheaths of cyanobacteria. *Experientia* 1993; **49** : 825-829.

60. Garcia-Pichel F, Sherry ND, Castenholz RW. Evidence for an ultraviolet sunscreen role of the extracellular pigment scytonemin in the terrestrial cyanobacterium *Chlorogloeopsis* sp. *Photochem Photobiol* 1992; **56** : 17-23.

61. Brenowitz S, Castenholz RW. Long-term effects of UV and visible irradiance on natural populations of scytonemin-containing cyanobacterium (*Calothrix* sp.). *FEMS Microbiol Ecol* 1997; **24** : 343-352.

62. Castenholz RW. Multiple strategies for UV tolerance in cyanobacteria. *Spectrum* 1997; **10** : 10-16.

63. Quesada A, Vincent WF, Lean-David RS. Community and pigment structure of arctic cyanobacterial assemblages. the occurrence and distribution of UV-absorbing compounds. *FEMS Microbiol Ecol* 1999; **28** : 315-323

64. Sinha RP, Klisch M, Vaishampayan A, Häder D-P. Biochemical and spectroscopic characterization of the cyanobacterium *Lyngbya* sp. inhabiting Mango (*Mangifera indica*) trees: Presence of an ultraviolet-absorbing pigment, Scytonemin. *Acta Protozool* 1999; **38** : 291-298.

65. Richter PR, Sinha RP, Häder D-P. Scytonemin-rich epilithic cyanobacteria survive acetone treatment. *Curr Trends Microbiol* 2006; **2** : 13-19.

66. Fleming ED, Castenholz RW. Effects of periodic desiccation on the synthesis of the UV-screening compound, scytonemin, in cyanobacteria. *Environ Microbiol* 2007; **9** : 1448-1455.

67. Garcia-Pichel F, Wingard CE, Castenholz RW. Evidence regarding the UV sunscreen role of a mycosporine-like compound in the cyanobacterium *Gloeocapsa* sp. *Appl Environ Microbiol* 1993; **59** : 170-176.

68. Sinha RP, Klisch M, Groniger A, Häder D-P. Ultraviolet-absorbing/screening substances in cyanobacteria, phytoplankton and macroalgae. *J Photochem Photobiol B: Biol* 1998; **47** : 83-94.

69. Sinha RP, Klisch M, Häder D-P. Induction of a mycosporine-like amino acid (MAA) in the rice-field cyanobacterium *Anabaena* sp. by UV irradiation. *J Photochem Photobiol B: Biol* 1999; **52** : 59-64.

70. Sinha RP, Klisch M, Helbling EW, Häder D-P. Induction of mycosporine-like amino acids (MAAs) in cyanobacteria by solar ultraviolet-B radiation. *J Photochem Photobiol B: Biol* 2001; **60** : 129-135.

71. Carreto JI, Carignan MO, Daleo G, De Marco SG. Occurrence of mycosporine-like amino acids in the red

tide dinoflagellate *Alexandrium excavatum* : UV-protective compounds? *J Plankton Res* 1990; **12** : 909-921.

72. Karentz D, Mceuen FS, Land MC, Dunlap WC. Survey of mycosporine-like amino acid compounds in Antarctic marine organism: potential protection from ultraviolet exposure. *Mar Biol* 1991; **108** : 157-166.

73. Dunlap WC, Williams DM, Chalker BE, Banaszak AT. Biochemical photoadaptations in vision: UV-absorbing pigments in fish eye tissues. *Comp Biochem Physiol* 1989; **93** : 601-607.

74. Dunlap WC, Yamamoto Y. Small-molecule antioxidants in marine organisms: antioxidant activity of mycosporine-glycine. *Comp Biochem Physiol* 1995; **112** : 105-114.

75. McClintock JB, Karentz D. Mycosporine-like amino acids in 38 species of subtidal marine organisms from McMurdo Sound, Antarctica. *Antarc Sci* 1997; **9** : 392-398.

76. Dunlap WC, Shick JM. Ultraviolet radiation-absorbing mycosporine-like amino acids in coral reef organisms: a biochemical and environmental perspective. *J Phycol* 1998; **34** : 418-430.

77. Sinha RP, Singh SP, Häder D-P. Database on mycosporines and mycosporine-like amino acids (MAAs) in fungi, cyanobacteria, macroalgae, phytoplankton and animals. *J Photochem Photobiol B. Biol* 2007; **89** : 29-35.

78. Oren A. Mycosporine-like amino acids as osmotic solutes in a community of halophilic cyanobacteria. *Geomicrobiol J* 1997; **14** : 231-240.

79. Cockell CS, Knowland J. Ultraviolet radiation screening compounds. *Biol Rev* 1999; **74** : 311-345.

80. Sivalingam PM, Ikawa T, Nisizawa K. Physiological roles of a substance 334 in algae. *Bot Mar* 1976; **19** : 9-21.

81. Oren A, Gunde-Cimerman N. Mycosporines and mycosporine-like amino acids: UV protectants or multipurpose secondary metabolites? *FEMS Microbiol Lett* 2007; **269** : 1-10.

82. Portwich A, Garcia-Pichel F. Ultraviolet and osmotic stresses induce and regulate the synthesis of mycosporines in the cyanobacterium *Chlorogloeopsis* PCC 6912. *Arch Microbiol* 1999; **172** : 187-192.

83. Portwich A, Garcia-Pichel F. A novel prokaryotic UV-B photoreceptor in the cyanobacterium *Chlorogloeopsis* PCC 6912. *Photochem Photobiol* 2000; **71** : 493-498.

84. Sinha RP, Sinha JP, Gröniger A, Häder D-P. Polychromatic action spectrum for the induction of a mycosporine-like amino acid in a rice-field cyanobacterium, *Anabaena* sp. *J Photochem Photobiol B: Biol* 2002; **66** : 47-53.

85. Sinha RP, Ambasht NK, Sinha JP, Häder D-P. Wavelength-dependent induction of a mycosporine-like amino acids in a rice-field cyanobacterium, *Nostoc commune* : role of inhibitors and salt stress. *Photochem Photobiol Sci* 2003; **2** : 171-176.

86. Scherer S, Chen TW, Böger P. A new UV-A/B protecting pigment in the terrestrial cyanobacterium *Nostoc commune*. *Plant Physiol* 1988; **88** : 1055-1057.

87. Böhm GA, Pfleiderer W, Böger P, Scherer S. Structure of a novel oligosaccharide-mycosporine-amino acid ultraviolet -A/B sunscreen pigment from the terrestrial cyanobacterium *Nostoc commune*. *J Biol Chem* 1995; **270**: 8536-8539.

88. Sinha RP, Ambasht NK, Sinha JP, Klisch M, Häder D-P. UV-B-induced synthesis of mycosporine-like amino acids in three strains of *Nodularia* (cyanobacteria), *J Photochem Photobiol B· Biol* 2003; **71** : 51-58.

89. Kumar A, Tyagi MB, Srinivas G, Singh N, Kumar HD, Sinha RP, Häder D-P. UV-B shielding role of $FeCl_3$ and certain cyanobacterial pigments. *Photochem Photobiol* 1996; **64** : 321-325.

90. de Chazal NM, Smith GD. Characterization of a brown *Nostoc* sp. from Java that is resistant to high light intensity and UV. *Microbiology* 1994; **140** : 3183-3189.

91. Ambasht NK, Ambasht RS. Plant responses to changing ozone and UV-B scenario: A review. *Proc Nat Acad Sci India* 2005; **75** : 159-168.

92. Sancar A, Sancar GB. DNA repair enzymes. *Annu Rev Biochem* 1988; **57** : 29-67.

93. Asata Y. Isolation and characterization of ultra-violet light sensitive mutants of the blue-green alga *Anacystis nidulans*. *J Bacteriol* 1972; **110** : 1058-1064.

94. Saito N, Werbin H. Purification of a blue-green algal deoxyribonucleic acid photoreactivating enzyme: an enzyme requiring light as a physical cofactor to perform its catalytic function. *Biochemistry* 1970; **9** : 2610-2620.

Proc. Nat. Acad. Sci. India, Sect. B, Vol. 78, Spl. Issue, 2008

Threatened wetlands need rehabilitation to enhance fish production in India

V.R.P. SINHA* and B.C. JHA**

Formerly at CIFE, Mumbai, India.

***Central Inland Fisheries Research Institute, Barrackpore, Kolkata-700120, India.*

**e-mail : sinhavrp@hotmail.com*

Abstract

India has sizeable area under freshwater wetlands (>0.15 million ha), spread over to various parts of the country. In addition to this the country also has 6740 km^2 of coastal wetlands, bulk of which is confined to Andaman and Nicobar Islands. Besides being the repository of aquatic biodiversity, these ecosystems perform a host of other utility functions like fisheries, food, fodder, fuel, medicine, tourism, water supply and irrigation. In recent times, however, most of them are in critical phase of ecological transition, as such need appropriate restoration measures, especially to enhance fish production and productivity.

Key words: wetland, aquatic biodiversity, ecological transition, fish production

सारांश

भारत मे मीठेजल की आर्द्रभूमि का काफी बडा क्षेत्र है (>0 15 मिलियन हेक्टेयर्स) जो देश के विभिन्न हिस्सो मे फैला हुआ है। इसके अतिरिक्त इस देश मे 6740 वर्ग किलोमीटर की समुद्रतटीय आर्द्रभूमि है जिसका अधिकाश हिस्सा अण्डमान और नीकोबार द्वीप समूह मे सीमित है। जलीय जैवविविधता के भण्डार होने के अतिरिक्त ये परिस्थितिकीय तत्र अनेक उपयोगी कार्यो का निष्पादन करते है जैसे मत्यकी, भोजन, चारा, ईधन, औषधि, पर्यटन जलापूर्ति तथा सिचाई। हाल के समय मे इनमें से अधिकाश परिस्थितिकीय सक्रमण की संकटापन्न अवस्था में है जिस कारण इनका उपयुक्त जीर्णोद्धार होना है जिससे विशेषकर इनकी मत्स्य उत्पादन क्षमता बढाई जा सके।

सांकेतिक शब्द : आर्द्रभूमि, जलीय जैवविविधता, पारिस्थितिकीय सक्रमण, मत्स्य उत्पादन

Introduction

India with its varied agro-climatic conditions, distinct ecological zones and a meeting ground of three major bio-geographic realms (Indo-Malayan, Eurasian and Afro-tropical), is bestowed with plentiful of inland waters including the sizeable area under wetland ecosystem. Wetlands are distributed across the length and breadth of the country, from highly cold arid zone of Ladakh to the warm arid zone of Rajasthan-Gujarat and also from wet Manipur to Monsoonic central India and to wet humid zone of southern peninsula. India has an estimated wetland area of > 1.5 million ha belonging to various categories. In addition to these India has 6740 km^2 of coastal wetlands, 80% of which is confined to Andaman and Nicobar Islands. In view of their importance as biodiversity reserves including the finest refuge of avian fauna, more than 98 wetlands in the country meet the criteria of RAMSAR convention while more than 68 wetlands have been designated as protected sites under Wildlife (Protection) Act 1972, supported by National Wetland Programme.

Wetlands are important in many ways, such as flood control, recharge and de-charge of ground water, shoreline stabilization, climate stabilization and carbon sequestrations. In addition to these, they also act as the repositories of over 40% of vertebrate fauna and more than twice as much invertebrate fauna and aquatic plants. They are also the source of lucrative fisheries, food, fodder, thatch, medicine, fuel, tourism, water supply and navigation. These utility functions have significant economic and biological values, as such conservation of wetlands is essential.[1, 2]

Wetland Resources

Indian wetlands can be broadly classified into three categories based on climate and geography, such as (i) Himalayan wetlands, (ii) Indo-Gangetic wetlands, and (iii) coastal wetlands. Himalayan region with its three distinctly different ecological terrain viz. West-

Table 1 - Wetland resources in India[6]

States	Area of Natural wetlands (ha)
Andhra Pradesh	100457
Arunachal Pradesh	20200
Assam	1,00,000
Bihar	224788
Goa	12360
Gujarat	394627
Haryana	2691
Himachal Pradesh	702
Jammu & Kashmir	7227
Karnataka	3320
Kerala	24329
Madhya Pradesh	324
Maharashtra	21675
Manipur	26600
Meghalaya	NA
Nagaland	210
Orissa	137022
Punjab	17085
Rajasthan	14027
Sikkim	1101
Tamil Nadu	58868
Tripura	575
Uttar Pradesh	12832
West Bengal	291963
Union Territories	
Chandigarh	NA
Pondichery	1533
Total	14,64,806

ern Himalayas, Central Himalayas and Eastern Himalayas has a number of important wetlands nurturing unique biota. The Ladakh and Kanskar region (4000 m above mean sea level) has many high altitude coldwater lakes, both saline and freshwater viz. Pangong, Tso, Morari, Chantau, Noorichan, Chassul and Honlay. These wetlands pass through extreme environmental variables like cold desert condition during winter and high solar radiation during the brief summer. In Kashmir Valley there are many wetlands like Dal, Anchar, Wulur, Haigam, Malgam, Hokersar, and Kranchu, which have unique biodiversity having tourism attraction.[3, 4, 5] Himachal Pradesh also has a number of natural wetlands (400 to 5000 m above the mean sea level) viz. Nako, Cander Natan, Chandertal, Surajtal, Khajiar, Kareri, Rewalsar, Renuka and Saketi. In Central Himalayas many wetlands exist spreading over to Sikkim, Assam, Arunachal Pradesh, Nagaland and Manipur. The Loktak Lake of Manipur with an area of 289 km^2 is one of the largest freshwater wetland of the region. Barring the wetlands located in the eastern Himalayas like Loktak Lake all other high altitude wetlands may not be attractive for commercial fisheries, but they are the unique reserves of precious germ plasm. Table 1 shows the wetland resources of the country.

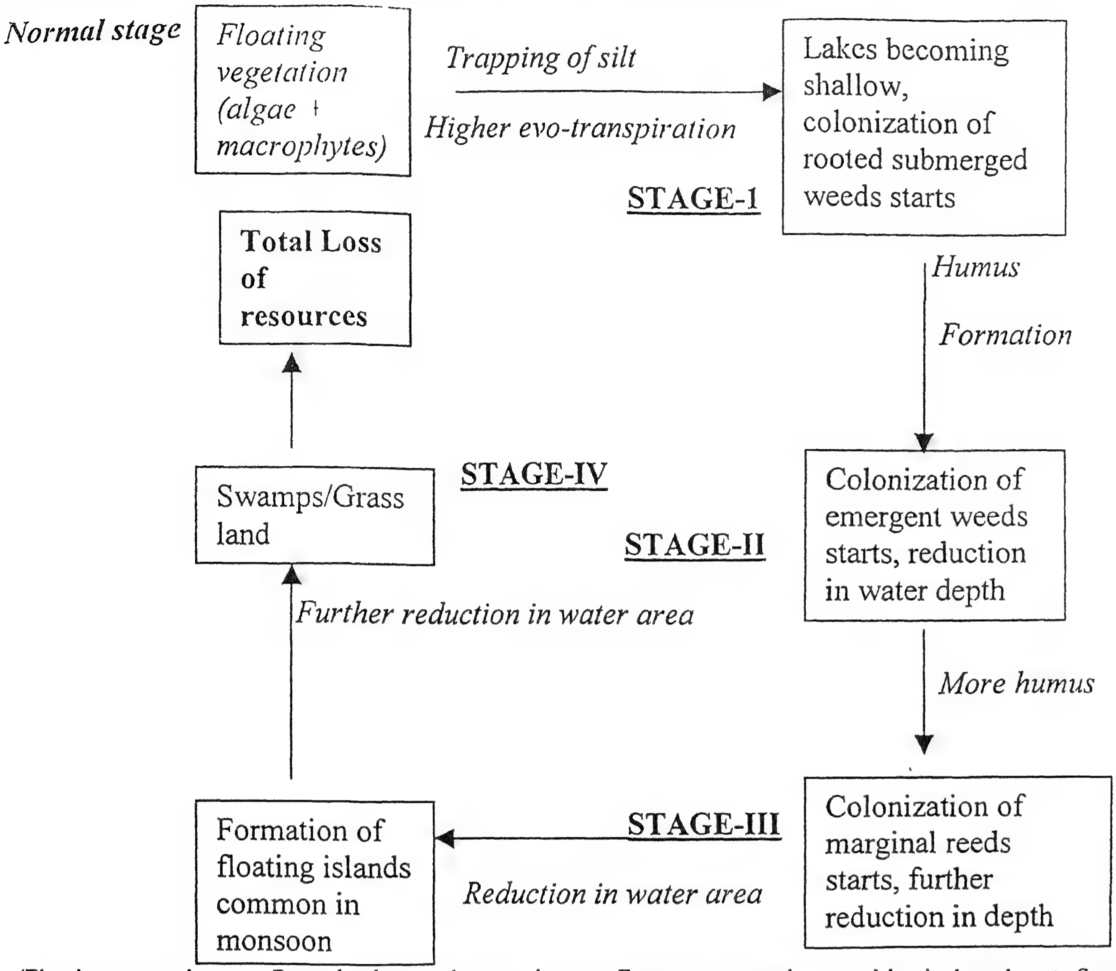
Among the wetlands, the floodplain lakes, widely distributed in the Ganga and Brahamputra river basins are highly lucrative from fisheries viewpoint. They are the traditional source of fish and fisheries, providing livelihood support to thousands of fishermen. These ecosystems, locally known as *beel, jheel, tal, pat, maun* and *chaurs*, have an estimated area of more than 2 lakh ha, spreading over to eastern and north-eastern states of India (Table 2).

Table 2 - Area and distribution of floodplain wetlands in India[7,8]

States	Area
Assam	1,00,000
Bihar	40,000
West Bengal	42,500
Uttar Pradesh	30,000
NE States	19,213
Total	2.32,213

General Ecology of Floodplain Wetlands

These water bodies are highly sensitive and fragile in nature, representing the transitional state between terrestrial and aquatic ecosystems. However, they are considered to be highly productive ecosystems with greater efficiency to convert solar energy into organic



(Floating vegetation —> Rooted submerged vegetation —> Emergent vegetation —> Marginal reeds —> Swamps —> Grass Land —> Loss of resources)

carbon due to the presence of rich nutrients available from natural source. It has been observed, however, that the rate of primary production is mainly through macrophytes (1000 mg C/m^2/day to 5000 mg C/m^2/day) as compared to phytoplankton (200 mg C/m^2/day to 1500 mg C/m^2/day), which could be construed as a serious aberration as the energy fixed through macrophytic chain is seldom transferred to fish growth effectively in the absence of efficient fish grazers. Evidently, bulk of the energy goes as waste without getting corresponding fish biomass. This is a typical example of weed choked aquatic system where the proliferation of plankton in general and phytoplankton in particular is invariably hampered due to poor availability of major nutrients in the ambient water (NO_3 Tr-2.0 mg/1, PO_4 Tr-0.05), which may be attributed to instant recycling of nutrients, from sediment to macrophytes and back to sediment.

The water quality in majority of wetlands is conducive for fish and fisheries, barring an isolated few, receiving very high pollution load. The problem of low productivity has, however, been observed in wetlands of North Bengal and Assam due to acidic basin soil.

The floodplain wetlands of Assam, Bihar, West Bengal and Uttar Pradesh have massive stands of macrophytes, indicating high level of eutrophication. The onus of ecological or fisheries management of these lakes, therefore, lies on tackling this problem, effectively. Numerous wetlands under Ganga and Brahamputra river basins have already been converted into swamps due to over growth of macrophytes and other anthropogenic interferences. A recent survey conducted by the Department of Fisheries, Bihar, indicates that more than 30% of the wetland resource of the state has either been reclaimed or have converted into swamps, during the last three decades. Similar has been the case in Assam and other states also. Loss of Dipper *beel* (Guwahati, Assam), East Calcutta wetland (West Bengal) and Jhapaha *maun*

(Mujaffarpur, Bihar) are some of the glaring examples. Besides, considerable shrinkage in the water area of Kabar Tal (> 2000 ha, Begusarai, Bihar) and Surha Tal (>2200 ha, Uttar Pradesh) are also indicative of gradual resource loss due to various natural and man-induced factors.

The biotic production of floodplain wetlands in India indicates two major groups dominating the niches, (1) thick stands of macrophytes in the water phase and (2) dense growth of gastropods in the benthic niche. Incidentally, both these dominant biotic produce are not in the grazing chain meant for harvestable fish crop in absence of efficient grazers. In fact, greater proliferation of aquatic weeds is the major problem whereas the higher abundance of gastropods is a fall-out of this menace.

Succession of macrophytes in wetlands

The diversity pattern and distribution of macrophytes in these water bodies are suggestive of a strong ecological succession. Most of the lakes are either in third or fourth stage of their ecological succession due to massive colonization of macrophytes vis-a-vis decreasing depth profile. The general succession of aquatic macrophytes in wetlands can be explained as under:

The surface coverage of aquatic vegetation like that of *E. crassipes* creates almost an under water desert due to shading effects, allowing very little sunlight to penetrate the column. Besides, continuous accumulation of decomposed or semi-decomposed vegetative matters form a kind of canopy over the oxidative-microzones at the lake sediment, which are responsible for the breakdown of organic matters, thus preventing the release of nutrients into ambient water. The nutrients released due to the mineralization of organic matter is instantly absorbed by the rooted macrophytes, leaving a little to support the growth and proliferation of phytoplankton, an important component of the grazing chain. Besides this, huge deposition of dead macrophytes at the bottom makes the environment almost anaerobic, accelerating the production of many harmful gases like methane. Further, excessive colonization of macrophytes, especially *Najas* spp. and charophytes, has a tendency to precipitate calcium, leading to '*marl*' formation thereby the process of '*calciphobe*' sets-in, which in turn repulse and eliminate a number of useful biota from the system.

Dissolved oxygen is one single factor, which not only regulates the type of biotic production, but also indicates the ecological health of an ecosystem. In a weed-choked aquatic environment the oxygen budget gets topsy-turvy with wide levels of fluctuations, ranging from very low level (even Nil), especially at dawn to super saturation level (<12 mg/l or even more), especially during dusk. Evidentially, the biotic communities including the fish fauna are subjected to extreme stress condition of very low to very high oxygen fluctuation (Table 3).

Table 3 - Dissolved oxygen levels in certain wetlands.

Wetlands	Weed biomass (Kg/m2)	Dissolved Oxygen (mg/l)
Motijheel, Motihari, Bihar	8.5-25.0	Nil-12.52
Kabartal, Begusarai, Bihar	7.3-30.5	2.5-12.06
Motipur, Mujaffarpur, Bihar	6.5-11.4	4.5-11.71
Surhatal, Balia, Uttar Pradesh	7.0-17.0	3.2-10.20

Based on the level of eutrophication, as indicated through the dynamics of macrophytes (6.5-25 kg/m^2), the wetlands of Eastern and NE regions of the country can distinctly be categorized into three ecological groups, as under:

<u>Wetlands with advanced stage of eutrophication (Eutrophic)</u>

They have high surface coverage of macrophytes (>80%) with distinct succession from floating to marginal reeds. Floating islands are common. They also show progressive reduction in the effective water area every year and become shallow to the tune of <1 m of water depth. While receiving pollution load externally; they are also subjected to perenniation of a few unwanted biota occupying the niche at the cost of natural biodiversity. Plankton grazing chain is seen virtually collapsed with stock and diversity of commercially important fish species declining alarmingly (Example: Motijheel, Brahampura maun, Kabar Tal in Bihar; Dipper beel, Assam; East Kolkata wetlands, West Bengal (approximately 7-8% of the total wetlands).

<u>Wetlands with manageable level of eutrophication (mesotrophic)</u>

Although such wetlands have high surface coverage of macrophytes, but <60% of with are yet to

reach the reed level. They are shallow but at least having >1 m of water depth. They are normally not getting external pollution load and formation of floating islands is rare. They are not subjected normally of perenniation of biota and thus natural biodiversity is not that much impaired but intact to a large extent. Plankton grazing chain is broken but not collapsed whereas stock and diversity of economically important fish species are under stress but remain sizeable in abundance (Example: > 80% existing wetlands in Assam, Bihar, Uttar Pradesh and West Bengal).

Wetlands with oligotrophic properties

Such wetlands have submerged macrophytes with surface coverage of > 40% with about >1.5 m water depth. They are invariably free from any pollution load and island formation does not take place. Biodiversity is not affected but plankton-grazing chain might be partially impaired. Stock and diversity of commercially important fish species are sizeable (approximately 10%-15% of the total wetlands under Ganga and Brahamputra basins).

General Ecology and Fisheries of Coastal Wetlands

Although lacustrine in appearance, the coastal lakes/wetlands are brackish-water in character. Their flora and fauna are mainly marine or estuarine as such wetlands have connections with sea in some form or other. The status and constancy of these connections largely determine the salinities and the types of fishery of coastal wetlands. However, the range of habitats is dependent on bathymetry, a function of local geological history and processes. The large surface area of these systems makes them unique. India has a number of coastal lakes on its East as well as West coasts. The Chilika (19°50' N, 85°30' E) and Pulicat (13°30' N, 80°10" E) lakes are the two best examples supporting important fisheries thereby providing the livelihood support to thousand of traditional fisher families.

Chilika Lake

The pear-shaped Chilika lagoon is considered to be one of the largest brackish-water lagoons in Asia and is one of the hotspots of biodiversity inhabiting a number of endangered species listed in the IUCN red list of threatened species like Irrawaddi dolphin. Chilika is a designated Ramsar site. It is an avian grandeur and the wintering refuge for more than one million migratory birds.

Chilika is surrounded by the alluvial plain of Mahanadi delta from the north, rocky hills of eastern ghats on the south and west and the Bay of Bengal in the east. The lagoon has a maximum length of 64.30 km, whereas the breadth varies between 5 km and 18 km. The water depth fluctuates between 0.38 m and 4.2 m. A total of 52 rivers and rivulets debouch into the lagoon draining a degraded catchments area of 3560 square km. The water-spread area of the lagoon, presently, varies between 1165 and 906 km^2 during the monsoon and the summer, respectively. There has been a significant reduction in the water-spread area of the lagoon between 1914 and 1989 (Balber[9]) mainly due to heavy siltation through the Daya, Bhargavi and Nuna rivers besides obstructed flushing of sedimented water through the constricted outer-channel connecting with the Bay of Bengal.

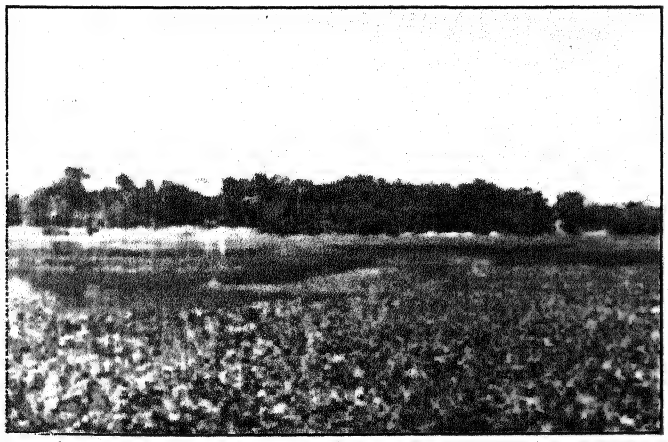


Fig 1 - A general view of a floodplain wetland with massive infestation of weeds

Fig 2 - A wetland in the process of being converted into a swamp

Till, recently, the 32 km long, narrow outer channel connecting the lagoon with the Bay of Bengal, near village Motto, had become non-functional owing to the shoal formation along the lead channel resulting which the tidal influx into the lagoon had considerably been reduced leading to significant erosion in salinity regime. This in turn had affected the brackish-water flora and fauna, adversely. On 23rd September 2000, however, a new mouth was created, artificially, reducing the length of the inlet channel, by 18 km. Consequently, there has been a quantum jump in annual fish yield from1745.75 t (1999-2000) to 11,988.88 t (2002-2003), immediately after such hydrological intervention. The opening of new-mouth improved the salinity profile of the lake and augmented the auto-recruitment of fish, prawn and crabs. It also helped in a hassle free breeding migration of fishes, prawns and crabs from the sea into the lagoon and vise-á-versa. During 1990s the infestation of freshwater invasive weeds like water hyacinth was a serious problem in the lake due to fall in salinity level. It increased from only 20 km^2 during seventies to 523 km^2 in 1990s. The situation has, however, improved considerably after the opening of new mouth during 2000 as the weeds are now restricted to the freshwater northern sector, only.

The Chilika lagoon has a profound impact on the socio-economics of the state of Orissa, both in terms of livelihood support and export earnings, since centuries. It supports a total of 12,363 fishermen families from 132 fishermen villages located in and around Chilika lake. The lagoon is known for its marine, brackish and freshwater fisheries besides one of the finest repositories of aquatic biodiversity including the dolphin and avian fauna. The lagoon is a potential source for high priced prawn and mullet fisheries contributing significantly to the livelihood security of a large fishing community and also to the overall state economy. The fish fauna of Chilika lagoon constituted, mainly, by four major groups *viz.* (i) euryhaline (ii) catadromous migratory (iii) anadromous migratory and (iv) freshwater species. The species richness in Chilika lagoon exhibits a cyclic pattern of change following hydrological characteristics and salinity gradient.

The restoration measures undertaken by the Chilika Development Authority, Bhubaneswar, have shown positive impacts, with manifold increase in productivity and considerable improvement in the biodiversity profile, which have ultimately been converted into the financial gain to the fishers. However, to make such gains sustainable, a number of pragmatic approaches would be essential so as to reap the benefits on a long-term basis. It would be essential to maintain the ecological health and making the fish productivity sustainable. CIFRI has made an in-depth study to formulate suitable measures for sustainable fisheries to address the livelihood issues on a sustainable basis after the opening of new mouth.

Pulicat lake

In recent years the Pulicate, with an average area of 280 km^2 and water depth of < 2 m, has almost turned almost into a freshwater lake, as was the scenario in Chilika lake during 1990s. The single channel connecting the lake with the sea has lost its relevance affecting the salinity regime thereby the fishery, significantly. The fish productivity of the lake was estimated at 39.59 kg/ha with an average annual fish yield of 1214 tonnes during 1970s (Kaliyamurthy[10]). Currently, however, the productivity of the lake has declined considerably (<12 kg/ha) so is the annual fish landing (<300 tonnes). The lake is in a total semblance with much reduced tidal ingress, greater proliferation of macrophytes, increased abundance of uneconomical freshwater fish species and considerable decline in mullet, prawn and crab fishery due to silted up connecting channel leading to significant decline of ecological profile of the lake, especially the salinity concentration. In the aftermath of changed ecology, the traditional fishers of the lake are the worst sufferers. Accordingly, this important coastal lake is a fit case for invoking suitable restoration measures on the line of experienced gained in Chilika lake, on an urgent basis, so as to safeguard the resource loss including the biodiversity and fisheries.

Vembanad Lake

There are a series of coastal lakes on the west coast of India, often referred to as "Backwaters" and among them Vembanad (9°30' N, 76°20' E) of Cochin, is important. Vembanad is a shallow brackish-water lake with an area of 24,000 ha, supporting more than 20,000 fishers in earning their livelihood. An estimated 7000t of finfish and shellfish is being harvested annually. More than 150 fish species, including the prized varieties like pearl-spot, mullets, the giant freshwater prawn *M. rosenbergii* and the penaeid prawn, inhabit the lake. The salinity concentration varies from almost freshwater to seawater, depending upon the rainfall. Over

the past three to four decades, the ecosystem has been threatened to the extent that the very entity of the lake is at stake due to increased human interventions. The most serious threat emanated from the construction of a barrage during 1976 at Thanneermukkom, which has divided the lake in two separate entities, obstructing the free-flow of water from either side. An area of 69 km^2, lying south of Thannermukkom, has been virtually been converted into a freshwater ecosystem with massive colonization of macrophytes, especially *Eichhornia crassipes* and *Salvania natans*, due to stagnation of water resulted from the the cutoff of tidal flow.[11] In the changed ecological status the fishery of *M. rosenbergii* has been affected significantly, from 305 tonnes during 1961 to 39 tonnes in 1989. The reduction is attributed to the barrage as it obstructs the return migration of the spent brooders as well as upward migration of post-larvae to the river. The overall fishery of the lake declined considerably, in recent times, seriously affecting the livelihood of fishers.12 It is imperative, therefore, that the continuity of the lake between both sides of the barrage would be essential for maintaining the fishery and biodiversity.

Kolleru Lake

Kolleru is the largest freshwater wetland in the east coast of India (surface area 245 km^2). It is located between the deltas of Krishna and Godavari rivers in Andra Pradesh. This prime wetland has been the flood-balancing reservoir of these two river systems. It is fed directly by two small seasonal rivers viz. Budameru and Tammileru while connecting to the Krishna and Godavari systems by over 68 inflowing drains and channels. The lake was known for its rich avian biodiversity, both migratory and resident (>20 million). The lake was notified as a wild-life sanctuary under India's Wild Life (Protection) Act, 1972, and designated a Ramsar site of International importance in 2002.

In recent times, however, the lake suffered due to increased anthropogenic interferences like digging-up of thousands of fishponds encroaching the lakebed to a large extent. Consequently, the lake biodiversity as well as natural fisheries suffered, adversely along with high colonization of macrophytes. Satellite images taken by the Indian Remote Sensing Satellite, IRS-1D, during 2001 indicate that around 42% (103 km^2) of the lake area has already been encroached under aquaculture while another 8% area has been reclaimed for agriculture crop. Evidentially, such a prime lake lost its relevance in terms of rich biodiversity reserve and a prime source of livelihood support to thousands of traditional fishers as the new sets of activities, either aquaculture or agriculture, helped only the rich farmers of the area at the cost of poor fishers depending on these lakes for centuries.

The average annual fish landing from the lake has been estimated at 2920 tonnes comprising a large number of fish and prawn species. However, four species *Metapeneaeus monoceros, Anabas oligolepis, Heteropneustes fossilis* and *Channa striatus* generally accounts for more than 64% of the fish catch[13]. The fish yield component of the lake comprised mainly of three groups viz. (i) Air-breathing species, (ii) riverine fish stock, and (iii) euryhaline fishes including the prawn, panaeids and palaenonids, migrating from the costal waters.

The ecology, biodiversity and fisheries of Kolleru lake has completely been shattered as more than 72% of the lake area has already been encroached upon as estimated during 2006 leaving behind the remaining thickly weed infested area. The lake remains no more an ideal destination for birds due to declined flora and fauna. So is the case of natural capture fishery. Kolleru lake can thus be considered a dying lake, which needs immediate restoration measures to conserve its rich biodiversity and fisheries, especially to address the livelihood concerns of traditional fishermen.

Serious Threats to Wetlands

Wetlands throughout the globe including India are one of the finest repositories of biodiversity, supporting wide range of plants, animals including avian fauna and microbes. Biologically, they are unparallel among the inland waters due to their high productive potential besides performing a host of utility functions of social, biological and geological importance. However, during the last few decades the wetlands have lost their pristine characteristics because of taming and damming of rivers, increased human interventions, indiscriminate exploitations to meet the competitive interests among various sectors of economy and water requirement for ever-increasing population of humanbeings, animals and birds.

These ecosystems are, literally, passing through a critical phase of ecological transition and are in the

process of being converted into "weed-bowls" at an alarming rate, leading to swampification. Available information on Indian wetlands, generated by various agencies including CIFRI, suggests that most of the wetlands are in advanced stage of eutrophication as indicative from the colonization of a dense to very dense stands of macrophytes. Greater proliferation of macrophytes is a disturbing trend impairing the ecological balance of these water bodies. Lopsided growth of biotic communities is of common sight in these water bodies with a few organisms tending to occupy the system replacing others. The biodiversity in general and the biota of economic importance in particular are on a declining spree. In fact, wetlands are facing serious ecological crisis, which is adversely affecting fish and fisheries too. Therefore, it has become imperative to restore the fishery of these lakes through appropriate restoration measures.

The lucrative fishery of commercially important fish of yester years has been replaced considerably by minnows, which have neither higher biomass production nor consumer preference. This singular change in wetland fisheries has led to considerable shift in occupation of traditional fishers to other petty odd jobs, resulting in massive loss of their livelihood support. Decline in fish catch has also put additional pressure on these ecosystems as the fishers are forced to resort to irrational fishing practices, such as rampant deployment of fined-meshed mosquito clothing nets, which has a disastrous impact on fisheries and biodiversity.

Man made changes in the river valley without caring of environmental impact assessment norms, resulted in draining or drowning the wetlands, mercilessly. In addition, the wetlands are subjected to various other forms of man-induced environmental problems like (i) Encroachment and abstraction of water (ii) Siltation, (iii) Weed infestation, and (iv) Pollution.

The most damaging trend, which has emerged in recent years, is that the people living around the wetlands have been encroaching upon these wetlands and draining them for agriculture, urban expansion and other purposes. The trend is similar in other countries for example, in China heavy demand of water for agriculture has resulted in the dry lake- beds on the Gianghan plains where 1000 lakes existed in 1950 but only 300 remained after three decades[14].

Siltation is also a major problem in most of the wetlands due to large-scale deforestation and other civil activities in their catchments, accelerating soil erosion and draining it into the wetlands. The wetlands are thus becoming shallow every year. An estimated 13 million tones of silt is deposited in Chilika Lake, Orissa, annually. Similar has been the case in many other important wetlands like Pulicat (Tamil Nadu), Surhatal (Uttar Pradesh), Kabartal (Bihar), Dipper beel (Assam), East Calcutta wetland (West Bengal), Loktak lake (Manipur) etc.

Under utilization of aquatic primary productivity results in colonization of weeds, especially nuisance weeds like *Eichhornia crassipes, Salvania natans, S. molesta* etc., which have become a serious threat adversely affecting the ecology and productivity of these wetlands.

Pollution (domestic, industrial or agricultural) is another factor responsible for the degradation of water quality of wetlands in India. The cumulative effect of various threats are becoming increasingly evident in the form of (i) decrease in biological diversity, especially endemic and economically important species, (ii) deterioration in water quality, (iii) shrinkage in effective water area and reduction in carrying capacity, (iv) decrease in fish and other faunal productivity, and (v) massive growth of weeds.

Fish and Fisheries of Floodplain lakes in Ganga and Brahmaputra basins

Floodplain wetlands had been one of the excellent capture fisheries resources in India, supporting thousands of traditional fishers in the states of Assam, Bihar, Uttar Pradesh and West Bengal. Such fishery resources have been subjected to a number of anthropogenic interference leading to devastating effect on fish biodiversity and fisheries The morphological changes brought about by damming and taming of rivers have changed the hydrography to such an extent that the connecting channels between the wetlands and adjoining rivers are no longer in existence to facilitate the recruitment of prized fish species in these systems, that provided excellent breeding ground for the parent stocks and for larval feeding and nursery grounds. The ingress of floodwater during the monsoon months used to flush the wetland environment by up-rooting the macrophytes colonized therein and to provide excellent opportunities for carp breeders for gonadal

hydration- a pre-requisite for breeding[15]. In absence of such natural phenomenon, most of the wetlands are devoid of auto-stocking of such fish species

Yield Pattern and Productivity Potential of Fish in Floodplain Wetlands of India

Based on the rate of energy assimilation and the energy reserves in the form of detritus, the productivity potentials of various wetlands in Assam, Bihar and West Bengal have been estimated by a number of workers[7, 8, 16-23] (Table 4).

Table 4 - Productivity potential in floodplain wetlands of India

States	Productivity Potential (kg/ha)
Assam	423-2324
Bihar	1000-2000
West Bengal	1000-2500
Uttar Pradesh	500-1000

In spite of moderate to very high productivity potential of floodplain wetlands in India, the average of present fish yield in unmanaged wetlands has been as low as 163 (Assam) to 859 kg/ha/yr (West Bengal). In certain managed wetlands, however, phenomenal increase in fish yield, > 3000 kg/ha/yr (Kola beel, West Bengal: Manjhaul lake, Bihar) has also been recorded, which is a function of a planned stocking and harvesting schedule.

Fish Catch Composition in Floodplain Wetlands

In recent times, the fish catch structure of floodplain wetlands has shown considerable change, from carp dominated fishery to minnows dominated fishery, indicating significant decline in the catch of prized fish species (Table 5). The fish species forming the catch were: *Labeo rohita, L. gonius, Catla catla, Cirrhinus mirgala, C. reba, Puntius sarana, Puntius spp., Wallago attu, Mystus seenghala, Ompak papda, Clupisoma garua, Channa marulius, C. striatus, C. gachua, H. fosilis, C. batrachus, Notopterus notopterus, N. chitala, Bagarius bagarius, Nandus nandus, Chanda nama, C. ranga, Chella bacaila* and other small varieties of fish and prawn.

Likely Succession of Fish Fauna in Wetlands

The fish community structure in Indian wetlands portrays a distinct ecological succession, which could be the function of changing trophic status due to increased man-induced interferences and greater colonization of macrophytes. The succession of fish species has been more prominent in closed wetlands, which have lost riverine connections as compared to live lakes retaining their connecting links. A broad outline of fish species succession could be traced as under:

Rehabilitation and Management of Fisheries in Wetlands

Concerted research carried-out in India, during the last two decades, on various aspects of wetland ecology and fisheries has helped in formulating the guidelines for fisheries enhancement in floodplain wetlands. The broad rehabilitation measures, which require immediate attention are :

Strengthening of auto-stocking in wetlands through hydrological interventions

In recent times, by and large the connecting links between the rivers and wetlands have become non-functional due to excessive silting in the face of river valley modifications and other anthropogenic interferences. Accordingly, the lakes have become closed and isolated systems without adequate ingress of fish brooders along with the floodwater for breeding. Rehabilitation of commercial fishery in these wetlands involves a recurring expenditure in the form of purchasing and transporting stocking material from outside and distant sources. Auto-stocking in these wetlands, therefore, could be the only viable alternative for sustainable fisheries. Thus it is imperative to revive the existing connecting channels through de-silting and maintaining them effectively to facilitate smooth entry of brood fish stock and juveniles from the riverine sources to facilitate auto-stocking.

Effective control of aquatic weeds

Most of the floodplain wetlands are reeling under the massive infestation of aquatic weeds of all kinds, such as floating, submerged, emergent and marginal, which in turn have hastened the process of swampification. The wetland fishery can never take off to its potential unless effective weed control measures are undertaken. There are a number of weed control devices, which can effectively be deployed to control

Table 5 - Fish catch composition in floodplain wetlands*

Fish catch	Assam	Bihar	West Bengal	Uttar Pradesh
Indian Major Carps	5.25-12.6	3.0-21.00	10-30.0	4.5-8.6
Minor carps	6.8-15.0	5.0-10.0	5.2-12.5	12.6-15.8
Catfish	10-45	14.99-80.00	8.0-35.0	15.6-40.5
Murrels	3.0-9.5	2.8-15.0	4.3-8.6	5.5-8.5
Feather-backs	7.5-15.5	35-9.6	2.5-3.8	2.5-4.5
Air-breathing fish species	4.5-5.5	4.0-8.0	3.5-4.5	1.5-3.2
Minnows	18.5-65.0	10-60.08	8.5-35.8	20.5-63.8
Hilsa ilisha	0.5-1.0	-	-	-

** Unmanaged/partially managed wetlands*

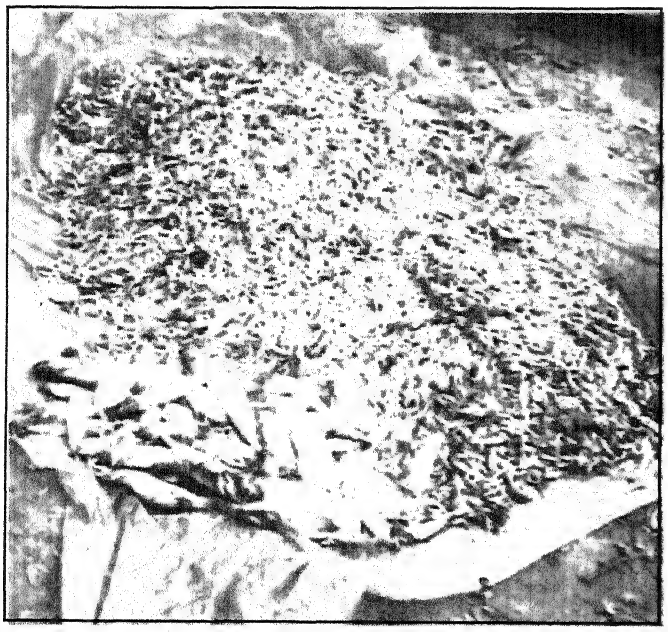


Fig. 3 - Fish catch composition from wetlands indicating greater dominance of minnows and predator fish species

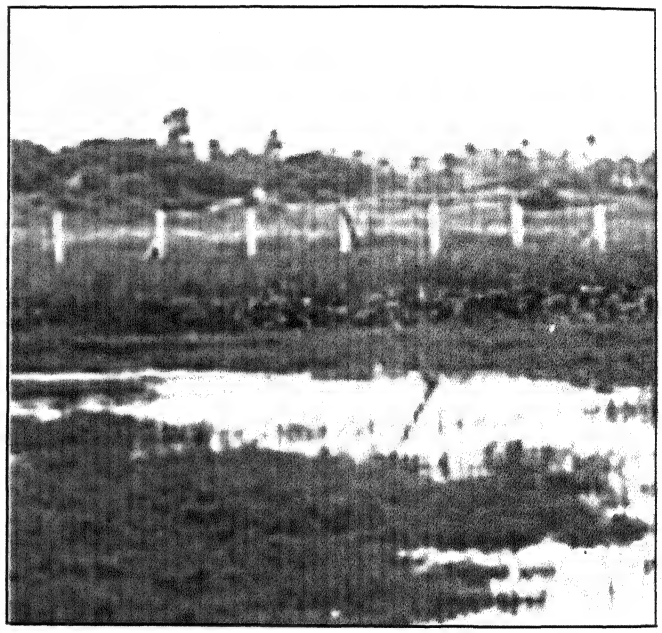
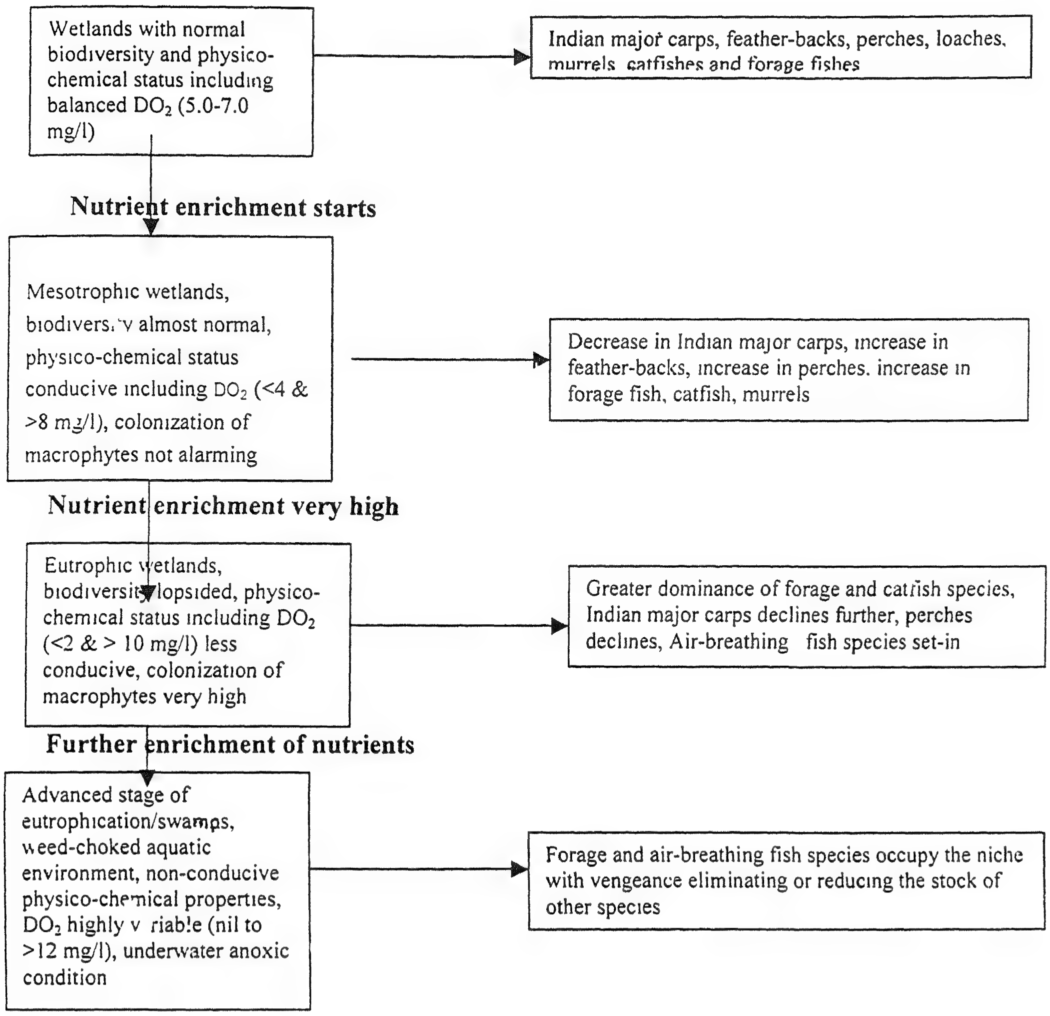


Fig 4 - View of a wetland being encroached upon for arable land.

this menace for making the wetlands better and congenial habitat for fish and fisheries[24, 25, 26, 27, 28, 29]. The problem lies mainly with the greater infestation of nuisance floating weeds like *Eichhornia crassipes* and to some extent two *Salvania species* (*Salvania natans, S. molesta*) as the submerged weeds like *Hydrilla verticillata, Vallisneria spiralis, Najas indica, N. minor* etc. can be controlled biologically through the introduction of herbivore fish species like *Ctenopharyngodon idella, Puntius pulchellus* and *P. dobsonii.*

Manual or mechanical methods of weed control may only be feasible in small wetlands (>100 ha). In case of larger wetlands a combination of control measures may have to be deployed, such as both mechanical and chemical. The technology demonstrated and experienced gained in case of Tamku Lake (500 ha) can be repeated in other large wetlands also. Application of 2,4-D sodium salt formulation (80% a. i.) achieved 90% clearance of water hyacinth within a week. Paraquat herbicide (Grammaxone) was also



used to kill the grass growing over the weed mats. A wetting agent (Dedonal) was mixed along with the herbicidal spray to facilitate adhesion over the leaf surfaces of the weeds.

Apart from the introduction of suitable fish species as bio-controller, success has also been achieved in the control of water hyacinth by introducing weevils, *Neochetina eichhorniae* and *N. bruchi*, in Loktak Lake, Manipur and Surhatal, Uttar Pradesh. However, at times, the weevils tend to migrate to the adjacent agriculture fields, damaging crops, in absence of water hyacinth.

Biomanipulation of fish stock and species for increasing production

In view of the dwindling fish stock of target species and absence of suitable species to utilize the vacant niches, biomanipulation would be essential to increase the production and productivity of wetlands. Presently, however, no scientific principles are being followed while stocking the wetlands. However, it would be essential to understand the complex relationship between food chains and patterns of energy flow in wetlands for developing appropriate stocking policies to augment the declining stock and species. In wetland ecosystems, two established routes for energy flow exist - the grazing chain and the detritus chain. The energy fixed by the producers can either be consumed directly by consumers through the grazing chain while the unused energy gets deposited as organic detritus to be utilized through the detritus chain. Presently, the wetlands have tremendous load of detritus, originating primarily through macrophytes, which

remains, by and large, unutilized. It may be profitable therefore, to exploit this energy reserve, which tends to lock in the mud, effectively, through the stocking of suitable detritivore fish species like *C. mirgala, Cyprinus carpio, Labeo calbasu* and others.

Bringing the wetlands under the fold of culture-based fisheries management

The wetland ecosystems are the ideal habitat for culture-based fisheries management wherein the principle of extensive culture and intensive capture should be followed. Stocking with large size fingerlings are essential to obtain high survival rate. To achieve success in culture based fisheries management, both stocking and harvesting schedules have to be well planned.

Popularization of integrated farming systems in wetlands

It would be essential that various facets of agriculture and animal husbandry including the fisheries got integrated rationally for judicious utilization of scarce water, waste, labour and land resources. Silt brought by flood and humus at the bottom is of great value for such integrated farming. Although there are many models of such integrated farming but integration of duck, poultry and pig farming along with horticulture with fish raising can be a profitable venture in this regard.

Introduction of new culture systems

Pen and cage culture have become very popular in entire south-east Asia, the far east and some east European countries. In India, CIFRI, Barrackpore has standardized the pen and cage culture systems for raising stocking materials as well as producing table size fish in wetlands and reservoirs. In an ox-bow lake in Bihar (Manika maun), Indian major carps were reared for six months in a pen made up of split bamboos yielding fish to the tune of 4 t/ha/yr. Recently, in certain wetlands of Assam rearing of fry to fingerlings was successfully done[30, 31].

Apart from using the pens and cages for raising the stocking materials, culture and rearing of 'high value-low density' fish species like ornamental fish species or giant freshwater prawn (*Macrobrachium rosenbergii*) or any other such species which has declined, but fetches relatively high price, such as *Gudusia chapra, Setipina phasa* or even perches like *Nandus nandus*, can be a viable economic activity increasing the income of the farming community, especially the women-folk who do not participate in active fishing activities. The wetlands in general and the floodplain wetlands in particular are known to nurture a number of such fish species. However, to make the activity sustainable and successful breeding protocol for such species would be essential to ensure sustained supply of fish seed.

Developing site-specific breeding and rearing protocols

It is a common practice in India to transport stocking material from far and distant places for stocking the wetlands. The mortality rate in such practices is invariably very high thus incurring considerable loss on each consignment. It would be prudent, therefore, to develop a self- sustained breeding and rearing protocol at the wetland site for procuring adequate and healthy stocking materials at a compatible cost. In order to make this programme successful the ideal landscape of the floodplains of a river basin, around the wetlands, can be utilized for breeding purposes. In this context 'Bund Breeding' of carps can be a viable proposition, which has been a traditional mode of breeding technique since long. The brood fishes can be maintained in cages or pens, installed in the wetlands. Rearing of fry to fingerlings can also be done in pens or cages. This practice would minimize the cost of stocking materials to a large extent, making the stocking programme economically viable. In this regard, however, all the wetlands may not be ideal for pursuing bund-breeding exercises, such as the tectonically depressed lakes like *chaurs* in Bihar and Assam, as they do not have the required gradient for conducting bund-breeding exercise. The existing abandoned connecting channels between the oxbows and rivers can also be utilized for this purpose with suitable modifications. In view of not recommending bund breeding in all the wetlands, it would be appropriate to take a cluster approach for stocking programme and select a wetland site for developing on-site breeding protocol either through bund-breeding or by installing potable hatcheries to breed the required fish species. It is essential to ensure the availability of quality fish seed in adequate quantity for stocking the wetlands. It is interesting to note that one of us (VRPS) had the privilege to be the consultant to the World Bank on a Ox--bow Lake Fisheries Development Project in Jessore, District of Bangladesh as far back as 1978 and the project when implemented with recommended stocking of fingerling was highly successful in increasing fish production to the tune of at least eight to ten times from the

lake. The in-built component in the project was to have a carp seed production unit at the selected lakes for production of fingerlings for stocking in the lakes (Sinha- Personal Communication).

Conservation of fish stock/biodiversity

Destructive fishing practices like use of *Chatti Jal* (fine meshed mosquito netting clothing) has been found highly damaging to the fishery and biodiversity of wetlands. It sieves through anything and everything making the water body virtually an ecological desert, as such this practice needs to be curbed through effective legislation and creating environmental awareness among the target groups. Wanton killing of fish juveniles, whatever stock comes from the riverine sources, is another factor, which is highly damaging to the fishery of wetlands. It would be, essential, therefore, to curb such irrational fishing practices either through effective legislation like closed season or creating awareness among the target group so as to allow the natural fishery of these wetlands to build and to conserve the precious fish germplasms and other biodiversity. Efforts have to be made to motivate people not to resort to such irresponsible fishery and if required providing them alternative livelihood for the period they are not allowed to fish in wetlands.

Conclusion

Wetlands being the common property resource have multiple stakeholders, as such subjected to multiple threats also. But it is a matter of great satisfaction that the importance of wetlands has been realized all over the world and global efforts are afoot for their preservation and rehabilitation. Yet, because of increasing population the pressure on wetlands for their conversion into terrestrial ecosystem will continue to grow. Coupled with this, abstraction of water and eutrophication are also expected to increase in wetlands. It will continue to be a great challenge as how to preserve this ecosystem and conserve its fish biodiversity and fisheries. It is important therefore that right to water is given to fish. It may seem difficult proposition apparently but once this right is given to fish, no manmade development can be pursued without considering their effects on fish biodiversity. It needs to be realized by all that fish is a great ecological player and fish culture is a tool to keep the ecosystem healthy, since ecological crisis starts soon the aquatic primary productivity is not utilized adequately or it remains underutilized. Further, water cannot be left on its own, as it brings death and devastation as it floods when uncontrolled and drains down to sea and ocean, but it brings life and prosperity when conserved and controlled. Similarly, silt and humus cannot be left on their own as they are useful when properly used, if not they solidify along with all the nutrients and thus resulting in their loss to the ecological chain. Their nutrients need to be recycled. The macrophytes like water hyacinth, which have occupied the wetlands with vengeance, can also not be left of their own as when present in manageable level they provide stability to the ecosystem, but if exceeds their limit they start posing many problems leading to hastening the process of swampification, and ultimately to terrestrial habitat.

Conservation and rehabilitation of flood plain fisheries would be essential for getting sustainable fish production, especially for the poorest of poor fishers. Some countries such as China and Bangladesh have done exceedingly well in augmenting fisheries basically by stocking fingerlings from extraneous sources. It is recalled by one of us (VRPS) that way back in 1978 that such proposal was also afoot in India but unfortunately it could not be pursued. However, Assam did initiate efforts for rehabilitation programme, sometime in early eighties, but it was only after 1990 that the World bank funded project was initiated along with reservoir fisheries development in certain states of India (Sinha-Personal Communication). It is reiterated that in future it is needed to aggressively pursue the efforts to prevent degradation of ecosystem and its precious resources to avoid loss of resource, productivity and biodiversity.

Acknowledgement

Authors are grateful to the National Academy of Science and to Professor R.S. Ambasht for inviting us to write the paper and to Dr. K.K. Vass, Director CIFRI for his help in writing the paper.

References

1. Hollis GE. The Functions of Floodplain wetlands within Integrated River Basin Management: International Perspectives. In: (British Council edition) Conservation and Sustainable use of Floodplain Wetlands. Kuala Lumpur: Asian Wetland Bureau, 1995; 1-8.
2. Denny P. Wetlands and Biodiversity. In. (British Council edition). Conservation and Sustainable use of Floodplain Wetlands. Kuala Lumpur: Asian Wetland Bureau, 1995; 9-12.

3. Zutshi DP. Impact of human settlement on the ecology of rural lakes of Kashmir. Final Report MAB Project. Department of Environment and Forests, Govt. of India. 1987.

4. Zutshi DP, Khan AU. On the lake typology of Kashmir. *Environ Physio Ecol Plants* 1978; 465-472.

5. Zutshi DP, Khan AU. Eutrophic gradient in the Dal Lake, Kashmir. *Ind J Environ Health* 1988; **30** : 348-354.

6. Anonymous. Inventory of Wetlands in India. New Delhi: Ministry of Environment and Forest, 1990.

7. Vass KK. Floodplain Wetlands-an important inland fisheries resource of India. Fisheries Enhancement of Small Reservoirs and Floodplain Lakes in India. *CIFRI Bulletin* 1997; **75** : 15-23.

8. Sinha M, Jha BC. Ecology and Fisheries of Ox-bow Lakes (Maun) of North Bihar- A Threatened Ecosystem. *CIFRI Bulletin* 1997; **74** : 1-109.

9. Balber SJM. Tropical Estuarine Fishes, Ecology and Conservation. London: Blackwell Science Ltd, 2000; 1-372.

10. Kaliyamurthy M. Organic production in relation to environmental features, nutrients and fish yield of Pulicat. *J Inland Fish Soc India* 1978; **10** : 68-75.

11. Unnithan VK. Ecology and Fisheries Investigation in Vembanad lake. *CIFRI Bulletin* 2001; **107** : 1-55.

12. Anon. CIFRI Annual Report, Barrackpore, Kolkata: 1995.

13. Ramakrishniah M, Gopalakrishnaya C, Rama Raju TS. Fluctuations in the fisheries of Kolleru lake Andhra Pradesh, India and the role of floodwater flow pattern on the fish abundance. *J Inland Fish Soc India* 1996; **28(1)** : 37-43.

14. Sinha VRP. Fisheries Research Planning and Management in Developing Countries. Delhi: Narendra Publishing House, 2005.

15. Sinha VRP, Jhingran VG, Ganapati SV. A review on the spawning of Indian major carp. *Arch Hydrobiol* 1974; **73(4)**: 518-536.

16. Jha BC. Beel Fisheries resources of Bihar and Uttar Pradesh. *CIFRI Bulletin* 1989; **63** : 11-23.

17. Jha BC, Chandra K. Kusheshwarsthan chaur area of North Bihar- status and prospects of fisheries development. *CIFRI Bulletin* 1997; **70** : 1-34.

18. Yadava YS. Beel fisheries resources of Assam. *CIFRI Bulletin* 1989; **63** : 1-10.

19. Yadava YS. Fisheries of Floodplain Lakes- A Fisheries Perspective. In: (British Council edition) Wetlands and Biodiversity. Conservation and Sustainable use of Floodplain Wetlands. Kuala Lumpur: Asian Wetland Bureau, 1995 16-23.

20. Sugunan VV, Sinha M Fisheries Enhancement of Small Reservoirs and Floodplain Lakes in India. *CIFRI Bulletin* 1997; **75** : 1-30.

21. Sugunan VV, Vinci GK, Bhattacharya BK, Hassan MA. Ecology and Fisheries of Beels in West Bengal. *CIFRI Bulletin* 2000; **103** : 1-70.

22. Sugunan VV, Bhattacharya BK. Ecology and Fisheries of Beels in Assam. *CIFRI Bulletin* 2000; **104** : 1-100.

23. Vass KK, Parmeswaran S. Development Issues in the Gangetic Floodplain. In: (British Council edition) Wetlands and Biodiversity. Conservation and Sustainable use of Floodplain Wetlands. Kuala Lumpur: Asian Wetland Bureau, 1995; 40-47.

24. Philipose MT. Fifty Years of Aquatic Weed Control in India. In: Varshney CK, Rzoska J. editors, Aquatic Weeds in South-east Asia. The Hague: W Junk, 1976. 215-223.

25. Ramchandaran V, Ramaprabhu T. Use of Ammonia for aquatic weed control-a review. In: Varshney CK, Rzoska J, editors. Aquatic Weeds in South-East Asia. The Hague: W Junk, 1976. 293-298.

26. Coulson JR. Biological control of alligator weed 1959-1972. A review and evaluation. Technical Bulletin US Department of Agriculture, 1977. 1547.

27. Dechoretz N. Control of submerged aquatic weeds in irrigation canals with fluridone. *Proc Western Society Weed Science* 1980; **33** : 1-133.

28. Murphy KJ, Barrett PRF. Chemical Control of Aquatic Weeds. In: Pieterse AH, Murphy KJ, editors. Aquatic Weeds-The Ecology and Management of Nuisance Aquatic vegetation. Delhi: Oxford Science Publication, 1990.

29. Pieterse AH. Biological Control of Aquatic Weeds. In: Pieterse AH, Murphy KJ, editors. Aquatic Weeds-The Ecology and Management of Nuisance Aquatic vegetation. Delhi: Oxford Science Publication, 1990.

30. Gorai BK, Jha BC, Nath D, Choudhury M. Penculture in Dek beel, Assam-A case study. *J Inland Fisheries Society of India* 2006; **38(2)** : 53-58.

31. Gorai BK, Sugunan VV, Jha BC. Rasing of stocking materials of Indian major carps in pen enclosures in selected floodplain wetlands of Assam, India. *Asian Fisheries Science*, 2007; **19** : 185-197.

Proc. Nat. Acad. Sci. India, Sect. B, Vol. 78, Spl. Issue, 2008

Mapping, monitoring and conservation of Mahanandi wetland ecosystem, Orissa, India using remote sensing and GIS

CHIRANJIBI PATTANAIK, C. SUDHAKAR REDDY* and S. NARENDRA PRASAD

Salim Ali Centre for Ornithology and Natural History, Deccan Regional Station, Hyderabad-500017, India.

**Forestry and Ecology Division, National Remote Sensing Agency, Hyderabad-500037, India.*

**e-mail : csreddy_nrsa@rediffmail.com*

Abstract

Mangrove forests are important component of coastal wetland ecosystems, depleting rapidly from nature due to anthropogenic pressure. The present study deals with periodic assessment and monitoring of the mangroves of Mahanadi delta, Orissa using remote sensing and Geographic Information System techniques. Satellite data of Landsat MSS for 1973, Landsat TM for 1990 and IRS P6 LISS III for 2004 were used to find out the changes that occurred in mangrove and other land cover categories during last 30 years. It was found that the delta is occupied by dense mangrove (12.6%), open mangrove (3.3%), aquaculture (12.9%) and agriculture (30.9%) in 2004. A loss of 2606 ha mangrove area and an increase of 3657 ha aquaculture area clearly depict high anthropogenic activities by local villagers. A significant increase of 726 ha plantations illustrates plantation activities taken up by the Orissa Forest Department to protect the coastal shore-line.

Key words : mangrove, wetland ecosystem, remote sensing, conservation, Mahanadi delta, Orissa.

सारांश

मैंग्रूव वन समुद्र तटीय दलदली परिस्थितिकी तंत्र के प्रमुख अवयव है। जिनका मानवीय क्रियाकलापो के अत्यधिक दबाव के कारण तेजी से ह्वास हो रहा है। प्रस्तुत अध्यन में सुदूर संवेदन एवं भौगोलिक सूचना प्रणाली द्वारा उडीसा राज्य मे स्थित महानदी डेल्टा के मैंग्रूव क्षेत्रों का आवधिक मूल्यांकन एव परिवीक्षण किया गया है। पिछले 30 वर्षो के दौरान मैंग्रूव एवं अन्य भूमि उपयोग श्रेणियों मे हुये बदलाव के अध्ययन हेतु 1973 के लैडसैट एम.एस एस , 1990 के लैडसैट टी.एम. एवं 2004 के आई.आर.एस.पी. 6, लिस-III उपग्रह आकडों का प्रयोग किया गया। प्रस्तुत अध्ययन से यह जानकारी प्राप्त हुई कि वर्ष 2004 में डेल्टा में सघन मैंग्रूव (12 6%), खुले मैंग्रूव (3 3%), जलकृषि क्षेत्र (12.9%) एवं कृषि क्षेत्र (30.9%) विद्यमान हैं। मैंग्रूव क्षेत्र में 2606 हे की कमी एवं जलकृषि क्षेत्र मे 3657 हे. की बढोत्तरी स्पष्ट रूप से स्थानीय निवासियों द्वारा की गई क्रियाएँ प्रदर्शित करते है। समुद्री तट रेखा के बचाव हेतु उडीसा वन विभाग के वृक्षारोपण कार्यक्रमों से 726 हे. क्षेत्र में बागानों की महत्वपूर्ण वृद्धि हुई है।

सांकेतिक शब्द : मैंग्रूव, आर्द्र भूमि परिस्थितिकी, सुदूर संवेदन, संरक्षण, महानदी डेल्टा, उडीसा

Introduction

Wetlands comprise only three to six percent of the earth's land surface area, but they provide human populations with a host of goods and services, including water quality maintenance, agricultural production, fisheries, and recreation[1]. Wetlands in India, as elsewhere are increasingly facing several anthropogenic pressures. Thus, rapidly expanding human population, large-scale changes in land use/land cover, burgeoning development projects and improper use of watersheds have all caused a substantial decline of wetland resources of the country[2]. Mangroves are one of the important components of the wetland ecosystem and found along the border of the sea and the lagoons extending along the banks of the river as far as the water remains brackish growing in swampy soils and covered by the sea during high tides. These are one of the most productive and biologically diverse wetlands of the earth. Mangrove vegetation mostly grows within the sheltered intertidal flat deltaic lands, funnel shaped bays, broad estuarine mouths, shallow or frequently tidal inundated coastlines. It provides critical habitat for diverse marine and terrestrial flora and fauna[3].

Landscape changes can be distinguished into conversion from one land cover type into another one and transformations within a given land cover type. A major step forward in the application of remote sensing data to landscape change detection is land

cover mapping[4]. Now-a-days mangrove forests are under severe threat due to various natural phenomena and biotic influences. Industrialization along the coastline is the major threat to the ecosystem as the sewage from industries is polluting these areas. Mangroves have been overexploited or converted to various other forms of land use, including agriculture, aquaculture, saltpans and for the construction of roads and embankments[5-6]. The extent of mangroves has also changed due to the accretion near river mouths, leading to the formation of new mangrove areas.

India has a total area of 4461 sq. km under mangrove cover, which is 0.14% of the country's total geographic area. It accounts for about 5% of the world's mangrove vegetation[7]. Nearly 57% of the mangroves are found along the east coast[8]. According to the Government of India report (1987), India lost 40% of its mangrove area during the last century[9]. Hence, there is an urgent need for conservation and management of the rest of the mangrove cover. An accurate and up-to-date information base on the status of mangrove vegetation, continually over time, is pre-requisite for a sustainable management of mangrove forest. Several floristic and ecological studies have been done in Mahanadi delta, Orissa by several botanists from time to time[10-12]. However, reliable and timely information on the nature, extent, spatial distribution pattern and temporal behaviour of mangrove forest is not available. Traditional field survey inside the mangrove swamps is extremely difficult. Remote sensing (RS) coupled with Geographical Information System (GIS) can be used as a useful tools to assess and monitor the effectiveness of mangrove restoration and conservation programmes with a cost effective manner. Several works have been carried out on mapping and monitoring of important mangrove wetland ecosystems in India and the world[13-18]. This paper highlights the use of RS and GIS to evaluate changes in mangrove vegetation and other land cover categories in the Mahanadi delta area from 1973 to 2004. The information can be useful in effective development and sustainable management of rest of the mangrove cover in Orissa coast.

Study area

Mangroves of Mahanadi delta are located in between 20° 18' to 20° 32' N latitude and 86° 41' to 86° 48' E longitude (Figure 1). It is surrounded by the Bay of Bengal in the east, villages of Kendrapara district in the west and north and the Mahanadi river in the south in state of Orissa, India. The area is intersected by a network of creeks (Kendrapatia Nala, Gobri, Nuna, Jambu, Kharnasi, Khola, Kaduamaadali and Barighar Galla Nala) with the Bay of Bengal in the east. The presence of innumerable meandering creeks, channels, islets with regular flushing by tidal waters and discharge of large quantities of fresh water for longer periods of time create suitable niches for the development of luxuriant mangroves in Mahanadi mouth region. The Mahanadi mangrove wetland comprising of 8 forest blocks namely Kantilo, Kendrapatia, Jambu, Bhitar Kharnasi, Bahar Kharnasi, Kansaridia, Hatamundia and Hutikola reserve forest. The soil texture ranges from coarse sand to silty clay and to clay. The organic matter content in soils[19] varies from 2.5 to 4.8 %. A maximum height of 6.0 m tidal amplitude can be observed near the river mouth and 3.5 m in the inner part during July-August, whereas, the maximum value reduces to 3.5 m in the mouth region and 2.0 m in the interior in February-March[20]. Generally, water salinity depends upon tidal amplitude, amount of fresh water discharged and the impact of rain. Salinity recorded a higher value of 11.5 to 19.9 ppt (parts per thousand) near to the sea, whereas it decreases to 0.3 to 0.7 ppt in the interior mangrove region[20]. The average rainfall is about 1500 mm, bulk of which is received during June to October. The maximum temperature recorded is 41°C and the minimum is 9°C during May and January respectively. Mean relative humidity ranges from 70% to 85% throughout the year.

Material and Methods

The data used in this study were comprised of three satellite datasets i.e. Landsat multi-spectral scanner (MSS) of 57 m resolution, Landsat thematic mapper (TM) of 28.5 m resolution and Indian Remote Sensing (IRS) P6 (Resources at-1) Linear Imaging Self Scanner (LISS) III of 23.5 m resolution. The details of path-row and the date of acquisition are given in table 1. In addition to this, forest management maps, Survey

Table 1 - Details of remote sensing data used

Satellite-sensor	Path-row	Date of acquisition
Landsat-MSS	149/46	17-01-1973
Landsat-TM	139/46	21-11-1990
IRS-P6 LISS III	107/58	13-01-2004

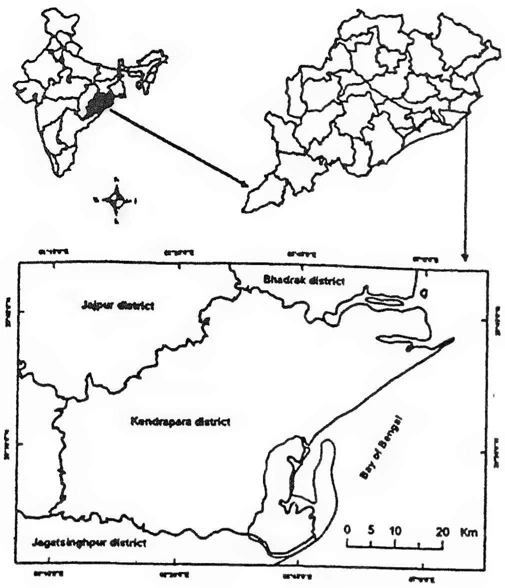


Fig. 1 - Location map of the study area.

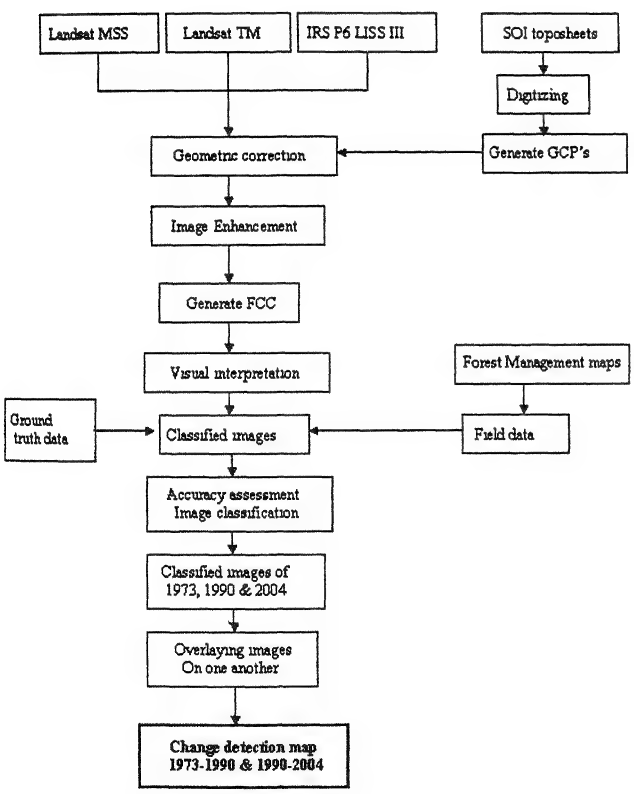


Fig. 2 - Flow chart indicating the methodology used to prepare mangrove change detection map.

of India (SOI) toposheets no-75L11 and 75L15 of 1:50000 scale, Global Positioning System (GPS) and magnetic compass were used for the study. The ortho-rectified satellite data of Landsat MSS and Landsat TM were downloaded from the Global Land Cover Facility (GLCF) website[21]. IRS P6 LISS III image was procured from National Remote Sensing Agency Data Centre (NDC), Hyderabad. Each image was enhanced using linear contrast stretching and histogram equalization to improve the image quality. It helps to identify ground control points (GCP). The IRS LISS III scene was geometrically rectified to digitally scanned topographic maps. The datasets were brought into Universal Transverse Mercator (UTM) projection and WGS84 datum. A nearest neighbour algorithm was used to perform the resampling procedure and the image to map registrations, which yielded a root-mean-square error of 0.75 pixels for LISS III data. The Landsat TM and IRS P6 LISS III images were geometrically resampled in relation to the Landsat MSS image to obtain the same spatial resolution (i.e. 57 m resolution). The area of interest (AOI) was masked out from all the three satellite images. The satellite data were visually interpreted on-screen on a WINDOWS computer using ERDAS IMAGINE 8.7 image processing software. A flow chart representing the methodology used here is given in Figure 2.

Visual interpretations of satellite imagery and reconnaissance survey of the area have been carried out for obtaining patterns of vegetation and other land features during January 2005 to December 2005. Ground truth data were collected with the help of False Colour Composite (FCC) maps of the study area (Figures 3a, 3b and 3c). The satellite imageries were interpreted and different land use and land cover categories were delineated on the basis of tone, texture, colour, pattern, etc. of the object on field (Table 2). Classified maps of 1973, 1990 and 2004 were generated (Figures 4a, 4b and 4c). The classified map of 2004 was corrected and finalized after thorough ground check. Three time frame classified maps were analyzed to find out the net change in area of mangroves and other land cover classes between 1973 and 2004 based on post classification comparison method using matrix model in ERDAS IMAGINE 8.7 software. The overall distribution of areas in mangrove cover and other land-cover categories (1973, 1990 and 2004) and the net changes in area (1973-2004) are estimated (Table 4).

Table 2 - Image interpretation key for mangrove and other land cover mapping

Land Cover Class	Tone	Texture	Shape	Pattern	Description
Dense mangrove	Dark red	Medium	Varying	Smooth	Tall dense trees
Open mangrove	Light red	Medium	Regular	Smooth	Short height tree species
Aquaculture	Light cyan	Coarse	Regular	Rough	Filled in water with perfect dykes
Plantation	Dark brown	Coarse	Regular	Rough	Patchy vegetation along the coastal belt and river beds
Mudflat	Pale blue	Medium	Irregular	Scattered	River sedimentation on the bank
Sand	Whitish	Fine	Regular	Smooth	Mound of sands with sparse vegetation
Water body	Dark or light blue	Smooth	Irregular	Scattered	Rivers and tanks
Agriculture with habitation	Light green or Pinkish	Smooth	Regular	Smooth	Crops with current fallow lands

Table 3 - Accuracy assessment of the study area

Classified Data	2004	
	UA*	**PA
Dense mangrove	80	100
Open mangrove	80	100
Mudflat	100	100
Aquaculture	100	100
Plantation	100	98.7
Sand	100	100
Water body	100	98.3
Agriculture	90	62.5
Overall accuracy	94%	
Kappa statistics	0.93	

*UA : User's accuracy (%); **PA : Producer's accuracy (%)

Results and Discussion

To determine the accuracy of the thematic map obtained using visual interpretation from 2004 image, an accuracy assessment was carried out. It is important that the quality of thematic maps derived from remotely sensed data be assessed and expressed in a meaningful way. This is important not only in providing a guide to the quality of a map and its fitness for a particular purpose, but also in understanding error and its likely implications, especially if allowed to propagate through analyses linking the map to the datasets[22-23]. The overall accuracy assessment stands at 94% in 2004 (Table 3). Spatial changes were assessed (Table 4, 5 and 6). A significant increase in aquaculture area and decrease in open mangrove area clearly depicts the anthropogenic pressure on mangroves. Of the total study area waterbody is the major category (34.2%) followed by agriculture (30.9%), aquaculture (12.9%) and dense

Table 4 - Distribution of areas in mangrove and other land-use categories (ha) in Mahanadi delta from 1973 to 2004.

Category	Area in 1973 (Ha)	Area in 1990 (Ha)	Area in 2004 (Ha)	Percentage of total area (2004)	Change (Ha) (1973-2004)
Dense mangrove	3356	2958	3581	12.6	225
Open mangrove	3532	1113	926	3.3	-2606
Aquaculture	0	2333	3657	12.9	3657
Plantation	7	575	733	2.6	726
Mudflat	459	713	292	1.0	-167
Sand	1039	644	707	2.5	-332
Water body	10102	10176	9709	34.2	-393
Agriculture	9866	9851	8756	30.9	-1110
TOTAL	28361	28361	28361	100.0	

Table 5 - Change area matrix from 1973 to 1990 (area in ha)

Land cover class	Dense mangrove	Open mangrove	Mudflat	Agriculture	Aquaculture	Plantation	Sand	Water body	Total (193)
Dense mangrove	1973	228	68	341	691	3	3	49	3356
Open mangrove	471	473	189	1115	970	12	10	292	3532
Mudflat	8	25	131	47	52	50	18	128	459
Agriculture	128	160	181	8337	614	172	51	223	9866
Aquaculture	0	0	0	0	0	0	0	0	0
Plantations	0	0	0	0	0	7	0	0	7
Sand	7	95	46	7	3	216	99	565	1039
Water body	370	131	97	5	2	115	462	8919	10102
Total (1990)	2958	1113	713	9851	2333	575	644	10176	28361

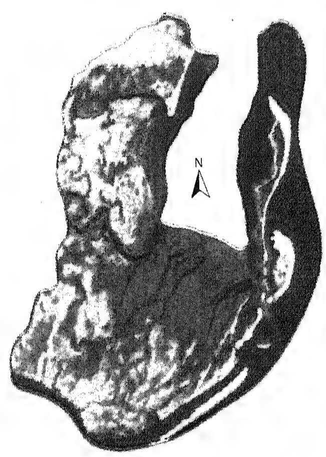


Fig. 3a. - FCC image of Landsat MSS, 17 January, 1973.

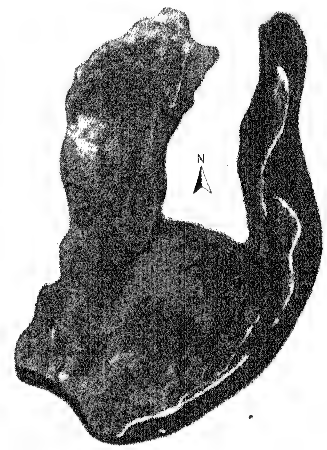


Fig. 3b. - FCC image of Landsat TM, 21 November, 1990.

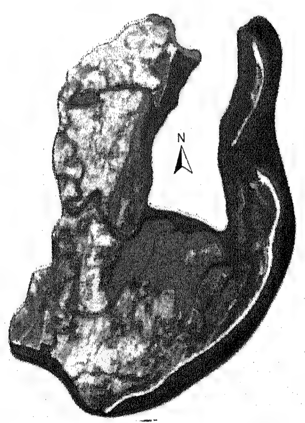


Fig. 3c. - FCC image of IRS-P6 LISS III, 13 January 2004.

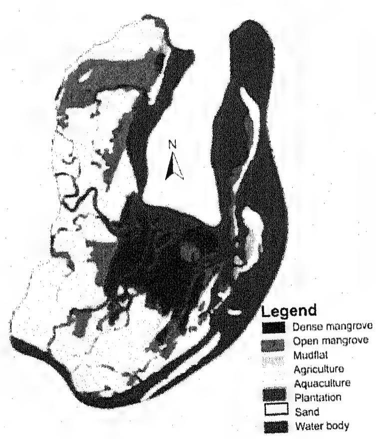


Fig. 4a. - Classified land-use/land-cover map of Mahanandi delta (1973).

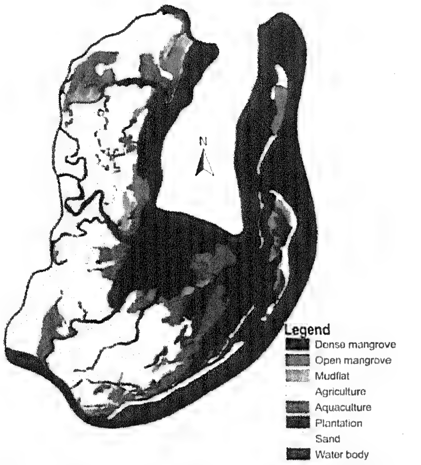


Fig. 4b. - Classified land-use/land-cover map of Mahanandi delta (1990)

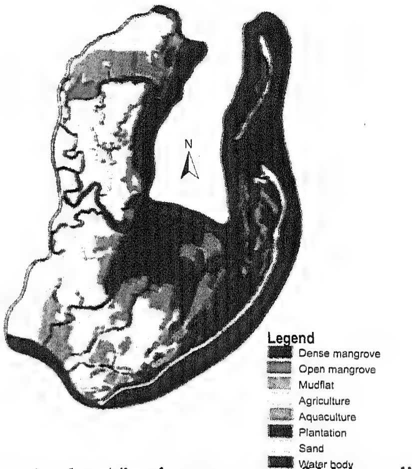


Fig. 4c. - Classified land-use/land-cover map of Mahanadi delta (2004)

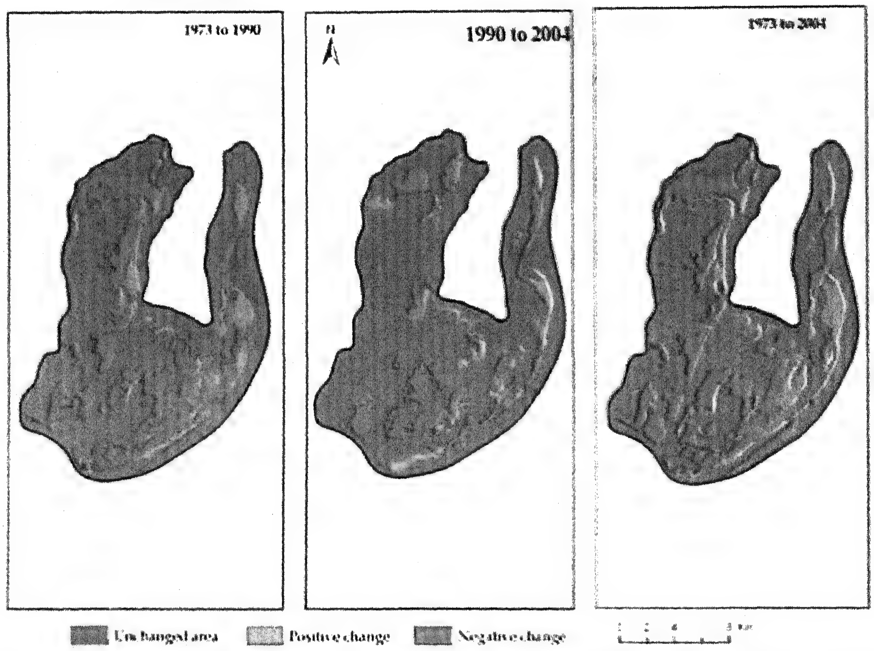


Fig. 5 - Mangrove and other land-cover changes in Mahanadi delta during 1973 to 2004.

mangrove (12.6%) in 2004 (Table 4). The overall change area statistics of different land cover categories from 1973 to 1990 and 1990 to 2004 is presented in Table 5 and 6. The overall positive and negative change of the study area is shown in figure 5.

Dense mangrove forest is typically a closed evergreen forest of moderate height, composed of species specially adapted to survive on tidal mud, which is partially sum-merged with salt water or brackish water. A significant increase of 225 ha mangrove forest was observed from 1973 to 2004. This is because of consequent regeneration of mangroves and protection from forest department. It has been observed that from 1973 to 1990, around 1383 of dense mangroves were converted to aquaculture (691 ha) followed by agriculture (341), open mangrove (228), mudflat (68) and waterbody (49). An area of 370 ha mangrove forest has been gained from conversion of waterbody. Change from water to mangrove may be due to sedimentation, and formation of new islands or tidal impact, whereas only 103 ha dense mangrove was lost during 1990 to 2004. *Avicennia officinalis* and *Avicennia marina*

Table 6 - Change area matrix from 1990 to 2004 (area in ha)

Land cover class	Dense mangrove	Open Mangrove	Mudflat	Agriculture	Aquaculture	Plantation	Sand	Water body	Total (1990)
Dense mangrove	2854	39	0	0	42	0	0	22	2958
Open mangrove	122	611	0	30	168	24	21	137	1113
Mudflat	62	172	225	174	69	7	0	5	713
Agriculture	22	24	0	8431	1344	0	1	28	9851
Aquaculture	148	68	3	44	2024	0	0	47	2333
Plantations	0	0	26	68	3	364	27	87	575
Sand	2	0	0	0	0	231	181	230	644
Water body	370	12	38	9	7	108	477	9154	10176
Total (2004)	3581	926	292	8756	3657	733	707	9709	28361

are the dominant species found in Bhitar Kharnasi and Bahar Kharnasi reserve forest. In Kansaridiha reserve forest, *Rhizophora mucronata, R. apiculata, Avicennia alba, Ceriops decandra, Lumnitzera racemosa* and *Excoecaria agallocha* are present in large numbers. Open mangrove forest is of low average height, characterized by mixed mangroves. This forest is found mostly in degraded and scattered condition. A net change in 2606 ha of mangrove forest has occured from 1973 to 2004 due to conversion to other land cover categories. The change in open mangrove area is observed highest from 1973 to 1990, as 1115 ha of agriculture land and 970 ha of aquaculture land has been formed. This is a clear indication of high anthropogenic pressure from surrounding villages. Mudflat is a low-lying muddy land that is covered at high tide and exposed during low tide. The vegetation in this area is generally herbaceous called as mudflat vegetation. *Sesuvium portulacastrum, Suaeda nudiflora, Salicornia brachiata* and *Suaeda maritima* grow predominantly in this area. It has been observed that mudflat area has also been reduced from 1973 (459 ha) to 2004 (292 ha). Analysis of the remote sensing data of 2004 reveals that an area 3333 ha of mangrove vegetation has been converted into aquaculture farms. Aquaculture farms were not found in the early 1980s and were introduced only in 1985. Most of the villagers who depend on traditional fishing left their job and started aquaculture farming by clearing mangrove forest. An overall loss of 1110 ha agriculture field was also converted to aquaculture farms during these 31 years. This is because of the fact that most of the villagers who were having agricultural fields shifted to profitable aquaculture farming. The Orissa Forest Department (OFD) and MS Swaminathan Research Foundation (MSSRF) has raised plantation of *Casurina equesetifolia* and *Rhizophora mucronata* in coastal sand and riverbeds respectively. The plantation area was considerably increased from 7ha (1973) to 733 ha (2004). The present study has shown that there is significant decrease of 2606 ha of open mangrove forest from 1973 to 2004.

Threats to the Mahanadi wetland

Despite government's several conservation efforts, the wetland area is shrinking day-by-day. The destruction of mangroves is due to heavy human pressure, indiscriminate felling, and conversion for different land uses[24]. Keeping in view the present land use, waterspread area, turbidity, aquaculture farming and aquatic vegetation, the threats to the Mahanadi wetland were identified as being due to factors discussed below.

Agriculture

A saline tolerant variety of paddy is the only crop being cultivated in almost all the villages surrounding the delta once in a year. Sometimes, groundnut and pulses are also grown in the elevated sandy areas from November to March.

Aquaculture

Brackish water aquaculture is generally being practiced in this region. Aquaculture farms were not found in 1973. It was introduced in deltaic zone around

1985 and increased to 3657 ha in 2004. Prawn is the major species cultivated in the aquaculture farms in a semi-intensive way. The rampant prawn farming has hastened the degradation of the mangroves of the region. There is evidence that large areas of mangroves were cleared in the Hatmundia reserved forest for aquaculture purposes[25].

Grazing pressure

Grazing is an important factor that affects the mangrove vegetation. The cattle and buffaloes from the nearby villages feed heavily on leaves, propagules and seedlings of *Avicennia* spp, *Sonneratia* spp, and *Bruguiera* spp[26]. Stunted mangrove vegetation is seen in almost all the areas of the Mahanadi mangroves wetland where cattle grazing is high.

Firewood collection

Most of the village people depend on mangrove forest for firewood. The average fuel used per household is about 14 kg per day, out of which 12 kg would be in the form of firewood obtained from mangrove forests[8]. There is a huge gap in demand and sustainable supply from the forests.

Household construction

Local people are using poles, studs for their house construction which are collected from these mangrove forests. *Phoenix* stems are used for construction of walls and leaves for thatching. *Heritiera* is used for making doors and windows, besides *Lumintzera, Xylocarpus* and *Avicennia* etc[26].

Fishing

The local fishermen are using this mangrove wetland for fishing purposes. There are about 34 species of fishes and 10 species of prawn found in the Mahanadi mangroves. Heavy pressure on the riverine systems, creeks and mangrove areas for fish, crabs, prawn seed collection has resulted not only in the loss of mangrove areas, but also the loss of breeding and spawning grounds for fishes, crabs and prawns.

Pollution

The pollution is the result of the nutrient input from sewage and effluents and washdown of fertilizers and pesticides from agricultural fields into the mangrove areas.

Conservation and management

The increased grazing pressure, pollution from industrial effluents, heavy use of mangrove forest for firewood, fodder, food, medicaments etc., augmented aquaculture farming, amplified in agriculture areas has resulted not only the reduction in wetland area but also deteriorated the ecosystem. So, necessary conservation efforts should be taken to conserve the pristine glory of Mahanadi mangroves. Alternative source of fodder should be provided to the cattle and their entry should be banned during monsoon season. Government should encourage the local people for *Casurina* plantation in their home gardens to meet the demand of firewood. Unsustainable harvesting of fishing and mechanized boats should be banned in shallow waters of mangroves. Rehabilitating or restoring the areas of destroyed or degraded mangroves through natural regeneration by planting mangrove seedlings. Awareness should be created among the people on the protective, productive and ecological role of mangroves. Artificial creeks should be made to flush the dry hyper saline soil with tidal waters.

The study of land use changes from the past to the present day contributes greatly to the prediction of expected future developments and plays a guiding role regarding the precautions to be taken when planning the future so that the environment in which we live is sustainable. With this study it has once again been seen that in the determination of changes in land use taking place over time remote sensing and GIS techniques are both very efficient tools. The information generated for the Mahanadi mangrove delta area will aid in understanding the spatial distribution of mangrove forests and periodic changes over more than 30 years. This will help the Orissa Forest Department in further planning and taking appropriate decisions for sustaining the remaining mangrove cover.

Acknowledgements

The authors are grateful to Dr. P.S. Roy, Deputy Director, Dr. M.S.R. Murthy, Head, Forestry and Ecology Division, National Remote Sensing Agency, Hyderabad and Director, SACON, Coimbatore for suggestions and encouragement. They are greatly indebted to Chief Wildlife Warden, Bhubaneswar for granting permission and providing field staff to do the research work. They thank the Department of Biotechnology (DBT) and Department of Space (DOS) for funding the

biodiversity characterization project under which this study was carried out. They are also thankful to Global Land Cover Facility Programme, University of Maryland, USA for providing Landsat satellite data.

References

1. Acreaman MC, Hollis GE. Water Management and Wetlands in Sub-Saharan Africa. Gland, Switzerland: IUCN, 1996.
2. Prasad SN, Ramachandra TV, Ahalya N, Sengupta T, Kumar Alok, Tiwari AK, Vijayan VS, Vijayan L. Conservation of wetlands of India - a review. *Tropical Ecology* 2002; **43(1)** : 173-186.
3. Kathiresan K. A review of studies on Pichavaram mangrove, southeast India. *Hydrobiologia* 2000; **430** : 185-205.
4. Getter DR, Cohen WB, Berterretche M, Maiersperger TK. Kennedy RE. Land cover mapping in an agricultural setting using multiseasonal Thematic Mapper data. *Remote Sensing of Environment* 2001; **76** : 139-155.
5. Gang PO, Agatsiva JL. The current status of mangroves along the Kenyan coast: a case study of Mida Creek mangroves based on remote sensing. *Hydrobiologia* 1992; **247** : 29-36.
6. Das P, Basak UC, Das AB. Restoration of the mangrove vegetation in the Mahanadi delta, Orissa, India. *Mangroves and Salt Marshes* 1997; **1** : 155-161.
7. Anonymous. State of Forest Report. New Delhi: Forest Survey of India, Ministry of Environment and Forests, Government of India, 2003. 21-22.
8. Kathiresan K. Conservation strategies for mangroves in India. *The Botanica* 2003; **53** : 61-75.
9. Anonymous. Mangroves of India; Status Report. New Delhi: Ministry of Environment and Forests, Government of India, 1987. 52-55.
10. Banerjee LK. Ecological studies on the mangals in the Mahanadi esturine-delta, Orissa, India. *Tropical Ecology* 1987; **28** : 117-125.
11. Sarma ALN, Wilsanand V. Littoral meifauna of Bhitarkanika mangroves of River Mahanadi system, east coast of India. *Indian J Mar Sci* 1994; **23(4)** : 221 -224.
12. Banerjee LK. Mangal formations of the Mahanadi delta: Exploitation and management. In: Singh KP, Singh JS, editors. Tropical Ecosystems: Ecology and Management. New Delhi: Wiley Eastern Publication, 1992. 289-294.
13. Ramachandran S, Sundaramoorthy S, Krishnamoorthy R, Devasenapathy J, Thanikachalam M. Application of remote sensing and GIS to coastal wetland ecology of Tamil Nadu and Andaman and Nicobar group of islands with special reference to mangroves. *Curr Sci* 1998; **75** : 236-244.
14. Selvam V, Ravichandran KK, Gnanappazham L, Navamuniyammal M. Assessment of community-based restoration of Pichavaram mangrove wetland using remote sensing data. *Curr Sci* 2003; **85** : 794-798.
15. Reddy CS, Pattanaik Chiranjibi, Murthy MSR. Assessment and monitoring of mangroves of Bhitarkanika wildlife sanctuary, Orissa, India, using remote sensing and GIS. *Curr Sci* 2007; 92(10) : 1409-1415.
16. Ramasubramanian R, Gnanappazham L, Ravishankar T, Navamuniyammal M. Mangroves of Godavari-analysis through remote sensing approach. *Wetlands Ecology and Management* 2006; **14** : 29-37.
17. Ramirez-Garcia P, Lopez-Bianco J, Ocana D. Mangrove vegetation assessment in the Santiago River Mouth, Mexico, by means of supervised classification using Landsat TM imagery. *Forest Ecology and Management* 1998; **105** : 217-229.
18. Filho PWMS, Martins ESF, Ribeiro da Costa F. Using mangroves as a geological indicator of coastal changes in the Braganca macrotidal flat, Brazilian Amazon: A remote sensing data approach. *Ocean and Coastal Management* 2006; **49** : 462-475.
19. Banerjee LK, Rao TA. Mangroves of Orissa Coast and their Ecology. Dehra Dun: Bishen Singh Mahendra Pal Singh Publications, 1990. 116-122.
20. Ravishankar T, Navamuniyammal M, Gnanappazham L, Nayak SS, Mahapatra G C, Selvam V. Atlas of Mangrove Wetlands of India (Part - 3 Orissa). Chennai: M.S. Swaminathan Research Foundation, 2004.
21. http://glcfapp.umiacs.umd.edu:8080/esdi/index.jsp (Global Land Cover Facility).
22. Arbia G, Griffith D, Haining R. Error propagation modeling in raster GIS: overlay operations. *International J Geog Inform Sci* 1998; **12(2)** : 145-167.
23. Veregin H. Integration of simulation modeling and error propagation for the buffer operation in GIS. *Photogrammetric Engineering and Remote Sensing* 1994; **60** : 427-435.
24. Anonymous. Conservation of Mangroves in India. New Delhi: Ministry of Environment and Forests, Government of India, 1990.
25. Anonymous. Coastal Environment. Ahmedabad: Space Application Centre, 1992.
26. Chadha S, Kar SC. Bhitarkanika : Myth and Reality. Dehra Dun: Natraj Publication, 1999.

Proc. Nat. Acad. Sci. India, Sect. B, Vol. 78, Spl. Issue, 2008

Carbon accumulation by macrophytes of aquatic and wetland habitats with standing water

JAN KVĚT[1,2]*, JAN POKORNÝ[1,3] and HANA ČÍŽKOVÁ[1,2]

[1]*Institute of Systems Biology and Ecology, Czech Academy of Sciences, Dukelská 145, CZ-37901 Třeboň, Czech Republic.*

[2]*University of South Bohemia, Branišovská 31, CZ-37005 České Budějovice, Czech Republic.*

[3]*ENKI, o.p.s., Dulelská 145, CZ-37901 Třeboň, Czech Republic.*

**e-mail : kvet@nek.trebon.cz*

Abstract

Data on the biomass and net primary production by aquatic macrophytes, collected in Central and Eastern European wetlands and standing shallow waters during 1960s, have recently been evaluated from the viewpoint of carbon content and its accumulation by the macrophytes. The macrophyte habitats are classified according to their nutrient status into oligo- meso- and eutrophic ones. The plant life forms are classified as emergent, floating-leaved (either free-floating or rooted) and submerged (both rooted and not rooted). The medium-term to long-term accumulation of carbon in the macrophytes is, within each life form, mostly inversely proportional to the trophic status of the habitat. The importance of the macrophytes' net primary production and both organic and inorganic carbon accumulation for whole aquatic and wetland ecosystems is discussed. Apart from many Charophytes, carbonate encrustations play only a minor role in the carbon accumulation by aquatic macrophytes. Stands of common reed (*Phragmites australis*) occurring in habitats of different trophy provide an example of a relatively rich organic carbon accumulation in wetland vegetation. The storage of organic carbon in any macrophyte community is the result of a balance between its net production and decomposition of the plant remnants.

Key words: climate change, plant biomass, net primary production, decomposition, organic carbon, carbonate encrustations.

सारांश

1960 से अब तक के मध्य और पूर्वी यूरोप के आर्द्र–भूमि और स्थिर छिछले जलाशयों के जलीय वृहत्पादपो की जीव मात्रा और स्पष्ट प्राथमिक उत्पादन के सूच्य का हालिया मूल्याकन वृहत्पादपों मे कार्बन–धारिता और कार्बन एकत्रीकरण जानने के उद्देश्य से किया गया है। वृहत्पादपो के निवास और उनके पोषक पद के आधार पर इनका वर्गीकरण अल्पपोषी, मध्यपोषी और तीव्रपोषी समूहो मे किया गया है। पौधों को उदगामी उत्प्लवनित पत्तियो वाले (जो पानी मे स्वतत्र रूप से तैरने वाले है या जडी है) और डूबे हुये (दोनो जडीय और बिना जड वाले) समूहो मे वर्गीकृत किया गया है। वृहत्पादप मे मध्य अवधि से लम्बी अवधि तक का कार्बन एकत्रीकरण, हर एक जीव प्रारूपो मे अधिकाशत· निवास स्थान के पोषी स्तर का प्रतिलोमतः अनुपाती होता है। वृहत्पादपो के, संपूर्ण जलीय तथा आर्द्र–भूमि के परितत्र मे स्पष्ट प्राथमिक उत्पादन तथा दोनों, कार्बनिक और अकार्बनिक, कार्बन के एकत्रीकरण की विवेचना की गई है। अनेक कैरोफाइटो को छोड कर, जलीय वृहत्पादपो मे कार्बोनेट की पपडी, कार्बन एकत्रीकरण मे केवल एक अल्प भूमिका ही निभाती है। आर्द्रभूमि की वनस्पति मे सामान्य नरकुल (*फ्रैग्माइट्स आस्ट्रेलिस*) जो भिन्न पोषी–स्तर के निवास स्थान मे पाया जाता है, तुल्नात्मक रूप मे अत्यधिक कार्बनिक कार्बन एकत्रीकरण का उदाहरण है। किसी भी वृहत्पादप समूह मे कार्बनिक कार्बन का सचयन, स्पष्ट उत्पादन तथा पौधे मे अवशेषों के सडने के बीच के सतुलन का परिणाम है।

सांकेतिक शब्द : जलवायु परिवर्तन, पौधे की जीव मात्रा, स्पष्ट प्राथमिक उत्पादन, सडना, कार्बनिक कार्बन, कार्बोनेट की पपडी पडना।

Introduction

Increase in carbon dioxide concentration in the atmosphere is considered to be one of the main factors responsible for the global climate change[1]. It is therefore worthwhile to investigate the role of different ecosystems in carbon dioxide assimilation from or release to the atmosphere or water. Also in wetlands, the accumulation of carbon taken up from the atmosphere or water in the form of carbon dioxide or bicarbonate depends primarily on the biomass and net production by the wetland and aquatic macrophytes. Hence it is the vegetation that plays a key role of a carbon fixer in the carbon budget of the respective wetland or shallow water ecosystem. Both climatic and trophic factors control the balance between net production and decomposition, the outcome of which is the net carbon accumulation by the vegetation[2].

Within a climatically relatively uniform area, in the present case Central and Eastern Europe, the life form of each macrophyte species is also an essential factor controlling the carbon balance. Data on macrophyte biomass and net production in temperate European and particularly Central and Eastern European wetlands and standing shallow waters, obtained mostly since 1960s[3, 4, 5], can be used for estimating the carbon content in and both organic and inorganic carbon accumulation by the macrophytes in habitats differing in their nutrient status (trophy) in which oligo- meso- and eutrophic habitats can be distinguished. Table 1 gives an overview of the wide range of trophic conditions in differently managed fishponds, many of which belong to the most eutrophicated aquatic/wetland ecosystems in Europe. This range thus covers almost all alternative trophic conditions in organically unpolluted or only slightly polluted wetlands and shallow standing water habitats. The aim of this paper is to evaluate, on the basis of the afore-mentioned data on macrophyte biomass, net production[6] and decomposition[7, 8], the potential of the aquatic and wetland vegetation occurring in habitats of different trophy, for the reduction/enhancement of carbon dioxide content in the atmospheric environment.

Material and Methods

The data evaluated in this synthetic survey have been collected mainly in the wetlands and shallow standing waters of Central and Eastern Europe. Here, also, a substantial amount of data has been gathered by the authors related members of the research team [3, 4, 9, 10, 11, 12] and incorporated into the Czechoslovak- Ukrainian synthesis[5]. A large-scale gathering of the data started in the mid-1960s, with the start of the IBP (International Biological Programme, 1965-74) within which research on the productivity of wetlands was duly represented[2]. Most of the data were obtained by the harvest method, with samples of macrophyte biomass being taken from plots of different sizes located in various plant communities of wetlands and shallow standing waters[13]. Many of these communities are dominated by only one species, which makes it relatively easy to classify the communities according to the dominant species and/or plant life form[14, 15]. Most of the harvested biomass samples included only aboveground biomass, but it is often possible to estimate the belowground biomass indirectly from belowground/aboveground biomass ratios obtained by direct sampling in analogous plant communities or in macrophyte cultures under simulated natural conditions[4]. For the transformation of aboveground biomass data into those of annual net primary production, different annual turnover factors have been employed. They vary between 1.05 and 1.5 for emergent macrophytes, 1.3 and 2.0 for semiemergent macrophytes, 1.5 and 3.0 for rooted floating-leaved macrophytes and 2.0 to 5.0 for submerged macrophytes. The average turnover factors of 0.3 and 0.5 have been applied to the belowground biomass of the emergents and semiemergents + rooted floating-leaved macrophytes, respectively, while a turnover factor of 1.0 has been applied to the roots of submerged macrophytes[4]. The production of free-floating macrophytes has been estimated as that of whole plants to which an average turnover factor of 3.0 has been applied[11]. The quoted rates of decomposition of macrophyte litter and/or detritus are derived from the literature[8, 16, 17, 18] while the data on the ash content and carbonate encrustations in macrophytes originate mostly from the author's unpublished analyses and from[5]. Within the IBP and the two successive Eureed projects of the EU (1993-1999), common reed (*Phragmies australis*) was investigated on a large scale. So, the data on its biomass and production in habitats of a different trophy are derived from publications synthesizing the results of the above programmes [2, 3, 5, 19, 20, 21, 22, 23, 24, 25]. The transformation factor of 0.4 between ash-free dry mass and organic carbon in the macrophytes' dry mass is based on the simplified assumption that all plant organic matter is polymerized CH_2O, which, of course, is never completely true. The contents of proteins and phospholipids reduce the carbon content in plant biomass to slightly less than 40 per cent. The carbon content calculated in the afore-mentioned way is thus slightly overestimated.

Results and Discussion

The higher plant (macrophyte) life forms are classified as emergent, semiemergent, floating-leaved (either free-floating or rooted) and submerged (both rooted and not rooted)[15, 16]. The wetland and shallow standing water habitats are classified according to their trophy as oligo-, meso- and eutrophic ones (see Table 1). Figure 1 shows the maximum values of seasonal biomass (net) production of the different life forms in habitats of different trophic status. All life forms of macrophytes are the least productive in oligotrophic habitats. Emergent and semiemergent

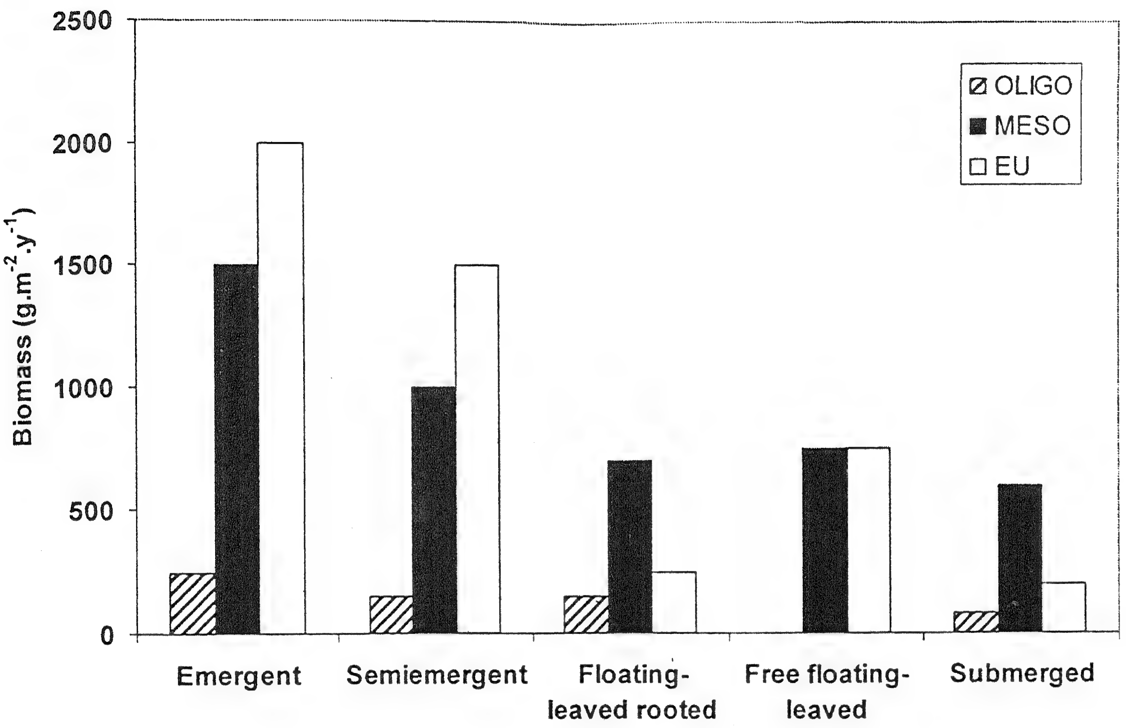


Fig. 1 - Maximum values of seasonal biomass production by different life forms of macrophytes in Central and East European water bodies and wetlands of different trophy (according to[5, 6, 16] and other authors).

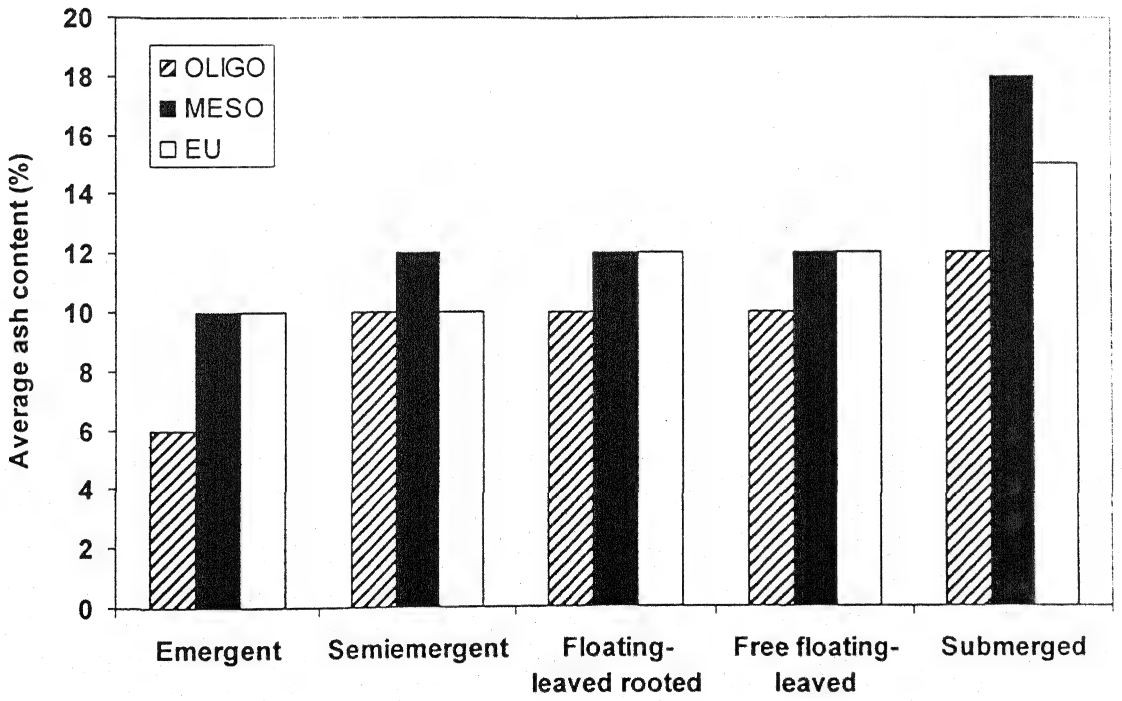


Fig. 2 - Average ash content in the dry mass of different life forms of macrophytes in Central and East European water bodies and wetlands of different trophy (based on the authors' unpublished analyses)

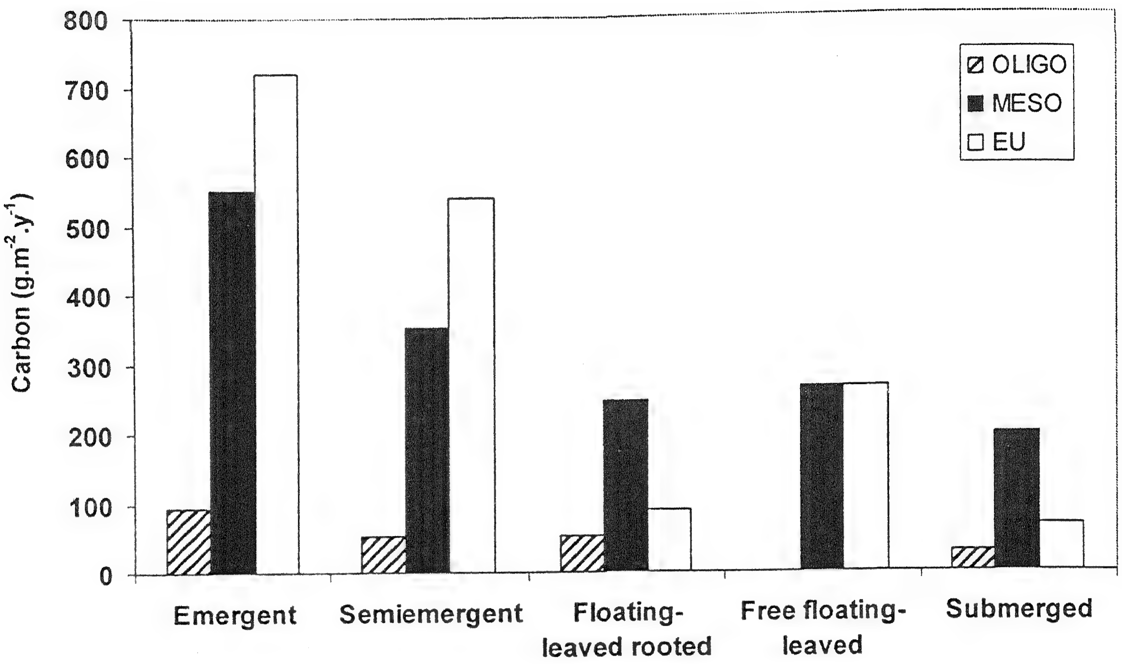


Fig. 3- Average amounts of carbon fixed per season by various life forms of macrophytes in water bodies and wetlands of different trophy. (Calculated from data given in Figs. 1 and 2 under the assumption of 40 % carbon content in ash-free macrophyte dry mass.)

macrophytes are most productive in eutrophic habitats whereas mesotrophic conditions seem to be most favourable for the other three macrophyte life forms. Free-floating (natant) plants, however, thrive equally well in eutrophic shallow waters because they escape from the competition with algae (mainly planktonic ones), which suppress the submerged macrophytes by shading and through competition for CO_2[11, 13, 26]. Many rooted floating-leaved plants and some emergent ones often suffer from anoxic conditions in eutrophic sediments[24, 27, 28, 29]. For that reason, mesotrophic habitats are the most favourable for such plants.

In order to assess correctly the organic carbon fixation in plant biomass, one has to be aware of the ash content in the macrophyte biomass (Fig. 2). The standing stock of the ash must be subtracted from the biomass in order to obtain the standing stock of plant organic matter[13, 30]. Of all the macrophyte life forms, the submerged macrophytes growing in meso- and eutrophic habitats exhibit the highest average ash content which, on the contrary, is lowest in emergent macrophytes. Oligotrophic conditions reduce the ash content in all the macrophyte life forms. Under the given trophic conditions, however, the average ash content varies relatively little among the macrophytes, except for submerged macrophytes (particularly Charophytes), which tend to be encrusted with carbonate. The silica encrusting the cell walls of some emergent macrophytes (grasses or sedges) usually does not increase the ash content above 10% of dry mass. (unpublished data by J.Květ *et al.*)

The average net amounts of carbon fixed in the macrophytes seasonal biomass (net) production (estimated at 40% of the produced ash-free dry mass) within one growing season are plotted in Figure 3. The picture obtained is similar to that for the seasonal biomass production (Fig. 1); only the differences between individual life forms and trophic conditions stand out more clearly when the slightly obscuring effect of the ash content on organic matter production is removed[30]. Again, the most efficient carbon fixers are the emergent and semiemergent macrophytes in eu- and mesotrophic habitats[4, 16].

Table 1 - Characteristics of different trophic status of water in Central European fishponds (L.Pechar, unpubl.)

Trophy	Total phosphorus ($\mu g.l^{-1}$) average (maximum)	Total nitrogen ($mg.l^{-1}$) average (maximum)	Chlorophyll content ($\mu g.l^{-1}$) average (maximum)	Dissolved carbon ($mg.l^{-1}$) average (maximum)	Particulate org. carbon ($mg.l^{-1}$) average (maximum)
Oligo	5(10)	up to 2	2(5)	3	0.3
Meso	30 (60)	up to 4	15(40)	6	2
Eutro to Hyper	200 (600)	4(7)	100(600)	15(40)	8(40)

Table 2 - Decomposition (loss of C org. within 1 year) in different life forms of macrophytes in standing waters of different trophy (according to different authors).

	Oligo [%]	Meso [%]	Eu [%]	Hyper [%]
Emergent	10-20	30	35	40
Semiemergent	10-35	50	50	85
Rooted floating-leaved	10-60	70	70	85
Free floating-leaved	10-65	80	80	-100
Submerged	10-50	75	75	-100

Table 3 - $CaCO_3$ encrustations in submerged macrophytes

Ca CO_3 encrustations ...... 120 g C per 1 kg Ca CO_3

Ca CO_3 content in submerged plants:

average .... 15 % d. w.

maximum ..... 45 % d.w. (Charophyta)

Maximum biomass production per year ($g.m^{-2}.y^{-1}$)	$CaCO_3$ ($g.m^{-1}.y^{-1}$)	C fixed ($g.m^{-2}.y^{-1}$)
80 g in oligotrophic biotopes	12-36	1.5-4
600g in mesotrophic biotopes	90-270	11-32
200g in eutrophic biotopes	30-90	<4-11

The net accumulation of organic carbon in an ecosystem is largely determined by the balance between the annual net primary production of plant biomass and the annual decomposition of the plant litter and detritus and of exudates from live plants. The share of exudates' decomposition in total decomposition is hard to evaluate[30], but the annual organic matter decomposition of dead macrophyte parts or whole plants has been assessed by a number of authors[8, 16, 17]. Based on these and other data, Table 2 presents average data on decomposition loss of carbon from the remnants of the various macrophyte life forms in habitats of different trophy. The table shows the decisive role of both the plant life form and habitat trophy on the annual decomposition. Among the plant growth forms the emergents are decomposed relatively most slowly while the free floating-leaved and submerged macrophytes are most rapidly. The relatively rapid biomass turnover in submerged and free-floating macrophytes and the subsequent rapid decomposition of their remnants naturally reduce the importance of these plants for a long-term or permanent carbon accumulation in the shallow standing water bodies they inhabit. For all macrophyte life forms, the decomposition is slowest in oligotrophic habitats and fastest in hypereutrophic ones. The net result of these differences is often the most effective accumulation of organic matter and carbon in oligotrophic

Table 4 - Ranges and averages of seasonal maximum aboveground biomass and average ash content, carbon content, harvestable carbon content and CO_2 contained in the average harvest (= 90 % of average biomass) of stands of *Phragmites australis* in littoral biotopes of different trophy. Data from various fishponds in the Czech Republic.

Trophy	Biomass range ($g.m^{-2}$)	Biomass average ($g.m^{-2}$)	Ash (%)	C ($g.m^{-2}$)	90% C	CO_2 ($g.m^{-2}$)
Oligotrophic	100-900	650	6	260	244	896
Mesotrophic	900-1286	1100	8	405	364	1336
Eutrophic	577- 1920	1500	10	540	486	1782
Hypereutrophic	739-3000	1900	10	684	616	2257

wetlands, such as raised bogs, and their least effective accumulation in highly eutrophic to hypereutrophic habitats, in spite of the high primary production of the vegetation occurring in the latter habitat types.

The question may be asked about the share of carbonate encrustations of submerged macrophytes in total carbon fixation in aquatic plants. Table 3 tries to answer this question on the basis of the data reported by[11, 13, 30] and other authors. The macrophytes growing in mesotrophic biotopes contain the relatively highest amounts of calcium carbonate and carbon fixed in it under the justified assumption of the average of 15% of the plant dry mass being formed by calcium carbonate. If, however, the calcium carbonate content rises to 45% of dry mass, as it sometimes does in Charophytes (Květ and Pokorný, unpublished data), the amounts of carbon accumulated in it and hence also in the plant biomass, become quite appreciable in comparison with the organic carbon amounts contained in the plant biomass. In view of the rather rapid turnover of biomass in submerged macrophytes (see above), the residence time of the carbonate carbon in the plants is short and the calcium carbonate of plant origin is deposited as marl on the bottom together with decomposing plant remnants.

Out of all macrophyte life forms, the emergent macrophytes store the largest amount of organic carbon in their both live and undecomposed dead biomass for the longest time[6, 16, 19, 31]. This can be well demonstrated on the example of common reed (*Phragmites australis*) occurring in habitats differing in their trophic status. Table 4 illustrates this fact as well as the potential of harvestable common reed stands for a temporary carbon dioxide removal from the atmosphere (ranging from several days when the reeds are used as fuel, to many years when they are used as thatching or building material). Yet, even if the reed serves as an "energy crop", the carbon dioxide released back into the atmosphere is just recirculated recent and not additional fossil carbon dioxide. While the data for meso-, eu- and hypereutrophic habitats presented in this table are based on great numbers of biomass assessments, the data for oligotrophic habitats are based on a rather small number of estimates[5, 21, 24, 32]. Nevertheless, the conclusion can be drawn from the data presented, that highly eutrophic conditions favour carbon fixation by emergent macrophytes.

Conclusions

The following conclusions can be drawn from the survey presented in this paper :

(a) Fixation of carbon depends on the life form of the macrophytes and on the trophic status of their habitats.

(b) Relatively highest carbon fixation occurs in emergent and semiemergent macrophytes in eutrophic biotopes and in floating-leaved rooted and submerged macrophytes in mesotrophic biotopes.

(c) In oligotrophic habitats, low primary production is often compensated by a low decomposition rate of macrophyte litter and detritus. Thus, the long-term result is a substantial accumulation of organic carbon as sapropel or peat. In eutrophic and, particularly, hypereutrophic habitats, high decomposition rate of macrophyte detritus limits organic carbon accumulation.

(d) $CaCO_3$ encrustations mostly play a minor role in carbon fixation by submerged macrophytes in comparison with their biomass except mainly the Charophyta. But it is a favourable circumstance for carbon dioxide removal from the environment that most of the carbon contained in $CaCO_3$ is deposited on the bottom and then remains in the sediment.

(e) As an example of emergent macrophyte vegetation, littoral stands of common reed (*Phragmites australis*) fix the highest amounts of carbon in their seasonal maximum biomass in eutrophic and hypereutrophic habitats.

Acknowledgement

This study was supported by the Czech grants VaV 640/18/03, NPV MŠMT 2B06023 and AVOZ 60870520.

References

1. IPCC 3rd Assessment Report: Climate Change 2001. http://www.ipcc.ch/pub/reports.htm

2. The Production Ecology of Wetlands. In: Westlake DF, Květ J, Szczepanski A, editors. Cambridge: Cambridge University Press, 1998. pp. 1-568.

3. Pond Littoral Ecosystems. Dykyjová D, Květ J, editors. Structure and Functioning. Berlin: Springer Verlag, 1978. pp. 1-464.

4. Hejný S, Květ J, Dykyjová D. Survey of biomass and net production of higher plant communities in fishpon. *Folia Geobot Phytotax* 1981; **16** : 73-94.

5. Macrophytes - Indicators of Changes in the Environment. In:Gejny S, Sytnik KM, editors. Kiev: Naukovaya Dumka, 1993. pp. 1-444.

6. Květ J, Westlake DF, Dykyjová D, Marshall EJP, Ondok JP. Primary production in wetlands. In: Westlake DF, Květ J, Szczepanski A, editors. The Production Ecology of Wetlands. Cambridge: Cambridge University Press, 1998. 78-168.

7. Úlehlová B. Microbial decomposers and decomposition processes in wetlands. *Studie ČSAV* 1976; **17** : 1-112.

8. Úlehlová B. The role of decomposers in wetlands. In: Westlake DF, Květ J, Szczepanski A, editors. The Production Ecology of Wetlands. Cambridge: Cambridge University Press, 1998. pp. 192-210.

9. Rejmánková E. The role of duckweeds (Lemnaceae) in small wetland water bodies of Czechoslovakia. In: Gopal B, Turner RE, Wetzel RG, Whigham DF, editors. Wetlands Ecology and Management. Jaipur: National Institute of Ecology and International Scientific Publications, 1982. pp. 397-403.

10. Pokorný J, Květ J, Ondok JP, Toul Z, Ostrý I. Production-ecological analysis of a plant community dominated by *Elodea canadensis* Michx. *Aquatic Botany* 1984; **19**: 263-292.

11. Pokorný J, Květ J, Eiseltová M, Rejmánková E, Dykyjová D. Role of macrophytes and filamentous algae in fishponds. In: Květ J, Jeník J, Soukupová L, editors. Freshwater Wetlands and their Sustainable Future, MAB Series no. 28, Paris, UNESCO and Boca Rayton: The Parthenon Publishing Group, 2002. pp. 97-124.

12. Hroudová Z, Hejný S, Zákravský P, Ostrý I, Květ J. Littoral vegetation of the Rozmberk Fishpond and its mineral nutrient ekonomy. *Studie ČSAV* 1988, **9** : 1-108.

13. Pokorný J, Květ J. Aquatic plants and lake ecosystems. In: O'Sullivan PE, Reynolds CS, editors. The Lakes Handbook, Volume 1. Limnology and Limnetic Ecology. Oxford: Blackwell Publishing, 2005. pp. 309-340.

14. Hejný S, Husák Š. Higher plant communities. In: Dykyjová D, Květ J, editors. Pond Littoral Ecosystems. Structure and Functioning. Berlin: Springer Verlag, 1978. pp. 23-64.

15. Hejný S, Segal S, Raspopov IM. General ecology of wetlands. In: Westlake DF, Květ J, Szczepański A, editors. The Production Ecology of Wetlands. Cambridge: Cambridge University Press, 1998. pp. 1-77.

16. Gopal B, Masing V. Wetland biology and ecology. In: Patten BC, editor. Wetlands and Shallow Continental Water Bodies. The Hague: SPB Academic Publishing, 1990. pp. 91-239.

17. Day JW Jr, Pieczyńska E, Úlehlová B Further fate of organic matter in wetlands. In: Westlake DF, Květ J, Szczepański A, editors. The Production Ecology of Wetlands. Cambridge: Cambridge University Press, 1998. pp. 169-191.

18. Dvořák J, Lišková E. Decomposition of *Glyceria maxima* in the littoral zone. In: Květ J, Jeník J, Soukupová L, editors. Freshwater Wetlands and their Sustainable Future, MAB Series no.28, Paris, UNESCO and Boca Rayton: The Parthenon Publishing Group, 2002. pp. 195-209.

19. Pieczyńska E, editor. Selected Problems of Lake Littoral Ecology. Warszawa: Wydawnictvo Uniwersytetu Warszawskiego, 1976. pp. 1-238.

20. Dykyjová D, Květ J. Mineral nutrient economy in wetlands of the Třeboň Basin Biosphere Reserve. In: Gopal B, Turner RE, Wetzel RG, Whigham DF, editors. Wetlands Ecology and Management. Jaipur: National Institute of Ecology and International Scientific Publications, 1982. pp. 325-355.

21. Čížková H, Lukavská J, Přibáň K, Kopecký J, Brabcová H. Carbohydrate levels in rhizomes of *Phragmites australis* in an oligotrophic and a eutrophic site: a preliminary study. *Folia Geobotanica et Phytotaxonomica* 1996; **31** : 111-118.

22. Čížková H, Strand JA, Lukavská J. Factors associated with reed decline in a eutrophic fishpond, Rožmberk (South Bohemia, Czech Republic). *Folia Geobotanica et Phytotaxonomica* 1996; **31** : 73-84.

23. Čížková H, Lukavská J. Rhizome age structure of three populations of *Phragmites australis* (Cav.) Trin. ex Steud; Biomass and mineral nutrient concentrations. *Folia Geobotanica* 1999; **34** : 209-220.

24. Cízková H, Pechar L, Husák Š, Květ J, Bauer V, Radová J, Edwards K.Chemical characteristics of soils and pore waters of three wetland sites dominated by *Phragmites australis*: relation to vegetation composition and reed performance. *Aquatic Botany* 2001; **69** : 235-249.

25. Rodewald-Rudescu L. Das Schilfrohr *Phragmites communins* Trin. Stuttgart: Scwarzerbart scher Verlag, 1974. pp. 302.

26. Pokorný J, Ondok JP Macrophyte photosynthesis and aquatic environment. *Rozpravy ČSAV sekce MPV* 1991; **91/4** : 1-117.

27. Braendle R, Crawford RMM. Rhizome anoxia tolerance and habitat specialization in wetland plants. In: Crawford RMM, editor. Plant Life in Aquatic and Amphibious Habitats. Oxford: Blackwell Publishing, 1987. pp. 397-410.

28. Armstrong J, Armstrong W, Zenbin W, Afreen-Zobayed F. A Role of phytotoxins in the *Phragmites* die-back syndrome? *Folia Geobotanica et Phytotaxonomica* 1996; **31** : 127-142.

29. Šantrůčková H, Picek T, Šimek M, Bauer V, Kopecký J, Pechar L, Lukavská J, Čížková H. Decomposition processes in soil of a healthy and a declining *Phragmites australis* stand. *Aquatic Botany* 2001; **69** : 217-234.

30. Wetzel RG. Limnology. Philadelphia: Saunders, 1975. pp. 743.

31. Straškraba M. Der Anteil der höheren Pflanzen an der Produktion der stehenden Gewässer. *Mitteilungen der Internationalen Vereinigung für Teoretische und Angewandte. Limnologie* 1968; **14** : 212-230.

32. Ksenofontova T. Morphology, production and mineral contents in *Phragmites australis* in different waterbodies in the Estonian SSR. *Folia Geobotanica et Phytotaxonommica* 1988; **23** : 17-44.

Proc. Nat. Acad. Sci. India, Sect. B, Vol. 78, Spl. Issue, 2008

Land-water ecotone ecology

R.S. AMBASHT** and NAVIN K. AMBASHT*

***Botany Department, Banaras Hindu University, Varanasi-221005, India.*

**Botany Department, Christ Church College, Kanpur, India.*

***e-mail : rsambasht@yahoo.com*

Abstract

Wetland margins overlapping with the adjacent upland margins are called the 'wetland ecotones'. They enjoy some of the best ecological conditions found in terrestrial and aquatic habitats and, therefore, are richer in biodiversity and rate of primary production. Wetland ecotones are the store-house of 'gene pools' and habitat of wild relatives of some cultivated plants. Most of the winter season migratory birds spend the daytime here in search of insects, molluscs and fishes as food and nights on trees. These ecotones often experience cyclic hydric to xeric conditions when the annuals of one season plants species emerge and flourish, the seeds and propagules of the other season undergo perennation, buried in the mud. World's largest segment of human population depends on rice (as food and fodder) which is essentially a wetland ecotone species. These ecotones are an extremely open system with lots of inflows, retention and outflows of materials and nutrients from uplands to aquatic ecosystems. The vegetation performs efficiently as conservers of soil, water runoff and nutrients and prevents aquatic bodies from upwelling and eutrophication.

Key words: wetland ecotone, soil conservation, ecotone biodiversity, cyclic succession.

सारांश

आर्द्र–भूमि का सीमा क्षेत्र जो सन्निकट के उपरिभूमि से मिलता है, आर्द्र–भूमि मध्यवर्ती क्षेत्र कहलाता है। इस प्रकार के क्षेत्र कुछेक सर्वश्रेष्ठ परिस्थितिकीय स्थितियों को दर्शाते है जो स्थलीय और जलीय स्थानो में पाई जाती है, अतः ये क्षेत्र जैवविविधता और प्राथमिक उत्पादन की दर से अधिक धनी है। आर्द्र भूमि मध्यवर्ती क्षेत्र, जीन–निधि तथा कुछेक संवर्धित पौधो के उद्धत सबधियो के निवास के भण्डार ग्रह हैं। जाडे के मौसम के अधिकांश प्रवासी पक्षी यहॉ दिन में कीटों, मोलस्का तथा मछलियों की तलाश मे तथा रात मे पेडों पर अपने निवास स्थान हेतु विचारण करते हैं। ये मध्यवर्ती क्षेत्र जलीय तथा शुष्क स्थितियो का चाक्रिक अनुभव करते है, जहॉ एक मौसम के वार्षिक पौधो की प्रजातिया उदगमित तथा विकसित होती रहती है वही दूसरे मौसम के बीज और प्रोपेग्यूल, गीली मिट्टी मे दबी हुई अवस्था में अपना चिरस्थायित्व बनाये रहते हैं। पृथ्वी की अधिकाश मानव जनसंख्या भोजन तथा चारे के लिये धान पर आश्रित है जो अनिवार्य रूप से आर्द्र भूमि मध्यवर्ती क्षेत्र की प्रजाति है। ये मध्यवर्ती क्षेत्र अत्यधिक खुले क्षेत्र है जहा उच्च भूमि से जलीय परितत्रो की ओर पदार्थों तथा पोषको का अंदर और बाहर की ओर बहना तथा इनका प्रतिधारण दिखता है। ये वनस्पतियां प्रभावी रूप में मृदा, बहते हुये पानी तथा पोषकों को संरक्षित करती हैं और जलाशयों को मिट्टी से पटने तथा यूट्राफिकेशन से बचाती है।

सांकेतिक शब्द : आर्द्र भूमि मध्यवर्ती क्षेत्र, मृदा संरक्षण, मध्यवर्ती क्षेत्र की जैवविविधता, चक्रीय वंशक्रम

Introduction

All kinds of wetland ecosystems' are flanked by uplands of terrestrial habitats. The transition zone between any two adjacent plant communities is referred as ecotone[1, 2]. At first Clements[3] gave the term 'tension zone' where the species of adjacent plant communities meet. Odum[4] has regarded "sharp transition between two or more communities", for example between forest and grassland or between soft-bottom and hard-bottom marine substrate as ecotone'. He has retained the term '*tension zone*' and the '*junction zone*' for the linear belt that is 'narrower than the adjoining community areas'. The ecotone is characterized by the overlapping communities of the adjacent areas, so that the diversity of species gets increased. Because of the fact that the ecological features of terrestrial and aquatic habitats join and provide a combined or added favourable conditions, the land-water ecotones enjoy not only greater diversity but quite often higher primary productivity. Therefore, the term 'tension' zone may be some what misleading as it should be regarded as a '*favoured zone*'. The plant density is also higher and all these together make a better standing crop biomass structure on per unit area, than the terrestrial and aquatic habitats. This characteristic of increased variety and density of community junctions is known as edge effect[4].

The Ecotone Concepts

The concept of community has been a subject of debate so far as the community boundaries are concerned. Some authors[5,6,7] have regarded communities as clearly distinct and discrete entities and have easily distinguishable boundary of a transition belt called ecotones. Some others[8,9,10,11], however, have regarded that the plant communities change as the habitat gradient or moisture conditions change very slowly and continuously. They have advocated the 'continuum' concept of plant communities. The ecotones under such a continuum concept can also be conceived as a visually distinct habitat type with its own characteristic species as well as the species of overlapping communities. Ordination technique is applied to explain the continuum whereas the zonal approach explains the discrete boundary concept. Under this concept also the ecotones are recognized as the meeting place of different communities. However, it must be emphasized that even though the habitat change may appear gradual or continuous, yet the plant communities because of their competitive (exclusion), cooperative (symbiotic) and co-action abilities show clear cut effects on ecotones more prominently than elsewhere. When biotic communities of both plants and animals are looked, it is at once noticed that co-evolution has led to the genesis of such species which essentially need the ecotone as well as the adjacent habitats, as in case of the amphibians. Some birds derive insects and small fishes from marsh of ecotones but for their nestling, live on the trees of nearby terrestrial systems. So the land-water ecotones have all the time emigration and immigration of certain species taking place on diurnal and seasonal basis, besides the more stable or permanent constituent species. The wetland ecotones have also during the course of evolution developed species adapted to them only as they are not found in the upland or aquatic bodies.

Land-water ecotones have assumed great importance as man has been encroaching and converting natural landscapes into pockets of ecotones. They provide as convergence point for rich biodiversity as the forests and truely aquatic bodies are losing their ecological integrity and identity due to deforestation, agriculture extension and upwelling of water bodies and landfill activities which create extended ecotones. These parcel of land around rivers and lakes as well in the coastal zones have to be regarded as sanctuaries for rich biodiversity of flora and fauna and home of wild relatives of domesticated plants and animals. Wetland ecotones, therefore, need special attention of experts and treatments by policy makers related to conservation of nature and natural resources for the benefit of both the present and future generations of mankind. Tiner[12] has discussed the "Reality or Myth" of wetlands as ecotones. He regards the wetlands as ecotones between truly aquatic and truly terrestrial habitats exemplified by marshes, wet meadows, shrub swamps, wooded swamps, bogs, muskegs, rivers etc. Fluctuations in the water level re-charge the ecotones with sufficient water to last upto the next events of floods, overflows, rainfalls and runoffs. Tiner's treatment of the subject has enlarged the scope of wetland ecotones considerably. Misra[13] in his pioneering paper on the ecology of low-lying lands had brought out the contrasting xeric and hydric features of hot summer, wet rainy and moist winter seasons at the same place. When the xeric species come up, the seeds and propagules of plants of other season pass their life in dormant phase in dry mud and when during rains they emerge, and grow, the xeric species pass their life cycle in dormant phase buried in the mud.

This concept, originally developed by Misra[13] in 1946, based on his succession studies of low-lying lands near Varanasi, was developed again in 1993 by Tiner[12] as "Cyclical Wetlands, based on his work on North American wetland ecotones, where the "plant community changes back and forth between one dominated by wetland species to one dominated by terrestrial species". The causal forces could be drastic hydrologic changes, fire in permafrost regions or other events responsible for hydrological periodicity. In India, as also elsewhere, in the village pond and lake wetlands, the central zone is truly aquatic and its area increases during the rainy season as it encroaches the peripheral ecotones, but as the dry phase begins, due to reduced water input and increased output of water lifted for irrigation and domestic use, the truly deep water zone shrinks and the ecotone area increases. The terrestrial species from neighboring uplands as well as the seed and diaspore bank lying buried in the lake bottom, emerge to give a perfect vegetational and faunal complex characteristic of ecotones. Ambasht and Ram[14] and Ambasht[15] have demonstrated such a phenomenon in their studies of a large Gujartal wetland near Jaunpur (U.P.) where the ecotone with dominance of *Oryza rufipogon, Paspalum scrobiculatum, and Eleocharis plantaginea* increase their area considerably during

the winter and summer seasons. Most of the migratory birds visiting the wetland in thousands during winter prefer to feed on the seeds of *O. rufipogon* and insects, worms and tiny fishes in the ecotone where as birds with webbed feet occupy the deepwater zones. *Eichhornia crassipes* has developed the ability to survive in water saturated ecotones quite effectively on losing their free floating habitat condition by the receding water from the margins. On further dying up, more hardy species for xeric situations like *Rumex dentatus, Alternanthera sessilis, Lippia nodiflora* come up.

Certain other types of cyclical ecotones have been described. Chabreck[16] while discussing the coastal marshes has recognized intertidal regimes of saline marshes and intermediate brackish areas as coastal ecotones. Tiner[17] has found that salt marsh ecotones have very high biodiversity.

Some Case studies of Ecotones:

Surhatal Wetlands

Ambasht[18] has studied Surhatal Wetland and ecotones for the biodiversity and role of ecotone vegetation in checking the erosion, thereby protecting the main lake from siltation and excessive runoff water. The ecotone area begins to increase from the end of october as the main water covered area begins to shrink and maximum ecotone area reaches by early June, i.e. before the outset of rains. The lake is of ox-bow type and connected with the main stream of Ganga river by Katahar Nala in the south only during high floods when the wetland gets charged with additional water. This is substantiated by the satellite imageries taken for this wetland separately during rainy, winter and summer seasons through the courtesy of NRSI Hyderabad. The cyclic ecotone belt out of the 3500 ha wetland site is 3000 ha in winter and 2200 ha in summer.

Faunal Diversity.

The entire wetland ecotone is subjected to intensive human activities of floating rice cultivation, mollusc collection, fishing and hunting or catching of migratory birds that visit the area in thousands. Even though hunting of birds is strictly prohibited, yet it is practiced with several traditional methods of catching them alive particularly during the night time. Cattle, sheep and goats also graze on the ecotone.

Quite often large herd of Nilgai (a kind of antelope) graze and damage the vegetation. In all 37 species of birds were recorded, of which in the ecotone the commonest ones are : chaha (*Capellia gallinago*), night heron (*Nycticorax mycticorax*), banmurghi (*Amauornis phoenicurus*), a few species of *Anas*, khanjan (*Motacilla macleraspatensis*) etc.

Floral Diversity

Amongst plants 50 species were selectively recorded by Ambasht[18], of which quite a few were present in one or another season and their phytosociological analyses were made. At Kaitholi site in the Surhatal wetland there are many important economically useful plants including those of medicinal value. Highest diversity, both in terms of variety and density of individuals of different species is seen during the rainy season followed by the winter and least in summer. *Cyperus rotundus and Cynodon dactylon* show even distribution all over the habitat with 100% and 85% frequency values respectively during the rainy season. Other very frequent species with 50% or more frequency are *Bonnaya brachiata, Ageratum conyzoides, Digitaria adscendens and Eclipta alba. Eclipta* is of high medicinal value for skin diseases. The vegetal cover decreases in winter. In summer the ecotone periphery towards the upland shows xeric conditions and stands of spiny plants like *Amaranthus spinosus, Argemone maxicana, Solanum xanthocarpum* and succulent *Portuaca oleracea* and drying plants of *Xanthium strumarium* with spiny seeds become characteristically present. This feature of ecotone behaviour is both temporal with the change of seasons and spatial with the distance from central aquatic to the upland peripheries. Besides naturally developing plant communities, a good part of the ecotone is used for the cultivation of a traditional variety of floating rice plants which in marshy areas are of normal 40-50 cm height, but as the water level rises the plant height sharply increases upto 200-250 cm height. It is a remarkable adaptation found in the traditional and not modern cultivars of rice. Surhatal wetland is a home of such as rare rice variety and its preservation as a 'gene pool' must be encouraged. At another sampling site Maritar of this ecotone, *Oryza* covers most of the area and other vegetal constituents are far less (21 species) as compared to Kaitholi site. Here, *Azolla* an aquatic pteridophytes with nitrogen fixing symbionts, blue-green algae, are very abundant as the receding water leaves them behind on

the mud surface. The density of *Azolla* recorded was 360 plants m^{-2} and its contribution to the nitrogen economy and rice productivity are bound to be significant. *Hydrilla verticellata* is dense on inner periphery of the ecotone with a density of 128 plants m^{-2}. The above two species together account of over 90% of the total density of all species (except rice). *Eichhornia* or water hyacinth has also developed adaptation to change over from its free floating normal forms to ecotonal mud forms with their otherwise floating roots turning to mud penetrating type. Their petiole 'floats' also lose their bulbous nature in the ecotones[18]. In the cultivated ecotone *Oryza* with 100% frequency had a very high density of 15.7 plants m^{-2}. This density at Maritar site was much higher than at Kartholi. The net primary productivity of *Oryza sativa*, calculated by positive summation of periodic biomass difference values was found to be 1.37 t ha^{-1} at Kaitholi and 1.56 t ha^{-1} yr^{-1} during growing season at Maritar. An aquatic fern *Ceratopteris* is also recorded at Kaitholi. The ecotone vegetation of this wetland site when tested for the rate of decomposition from the litter collections, showed that as much as 80%-90% of the litter placed in nylon bags were lost within the first forty days of the experiment.

Experiments on Surhatal ecotone vegetation, soil and water conservation

Besides acting as the basket of biodiversity of gene pools, the wetland ecotone plays a key function of protecting the main water body against input of soil and water. Otherwise, the aquatic bodies, like rivers and lakes get upwelled due to silting, and turn eutrophic due to high level of nutrients. Both are ecologically harmful. How far, the ecotone vegetation is effective in playing such roles at the Surhatal ecotone has been studies by one of the author (R.S. Ambasht[18]) using the technique evolved by him[19,20]. At Kaitholi site, 4 m^2 plots of vegetated ecotone and 4 m^2 of vegetation cleared plots in suitable replicates were subjected to identical water showering of 25 litres/m^2 equivalent to 25 mm natural rainfall. The runoff water and eroded soil were collected in prepared pits. Lined with thick polythene sheet to prevent infiltration or seepage. The experimental measurements of soil erosion and water runoff for each of the rainy winter and summer seasons were recorded and computed for seasonal as well as annual erosion and runoff. The conservation value (CV) percentage by the ecotone vegetation was calculated using the formula developed by Ambasht[19]. At Kaitholi (7^0 slope) the water CV in rainy, winter and summer seasons were 41%, 58% and 65% respectively whereas the soil CV for corresponding seasons were 93.3%, 94% and 95%.

In terms of soil quantity, the recorded eroding across the ecotones was 1.54 t ha^{-1} in rainy season, 0.15 t ha^{-1} in winter season and no erosion in summer as against the annual soil erosion from bare (devegetated) land of 23.34 t ha^{-1} yr^{-1}. The results show how effectively the ecotones with their natural vegetation protect the adjacent water bodies like rivers or lakes.

Sarnath Wetland

Ambasht[21] has recently evaluated the conservation potential of *Typha anguistifolia* and found an exceptionally high efficiency of 98.4% soil C.V. The ecotones play strong buffering influence between adjacent communities and as 'sink' for runoff material across it. This species is common in Sarnath wetland margins.

Around Rihand Dam :

Some other cases of ecotones in respect of their conservation were briefly discussed by Ambasht and Ambasht[22,23]. Ambasht *et al.* have studied the ecotone on the margin of G.B. Pant Sagar at Renukoot (Sonbhadra-UP) in great details. The intensively studied species bordering the slopes of the upland are *Leonotis nepetifolia, Cassia tora, Ageratum conyzoides, Parthenium hysterophorus and Sida acuta.* Kumar *et al*[24,25] performed showering treatments of high intensity on similar and equal sized plant covered and bare lands and collected runoff soil and water for their conservation as well as for nitrogen and phosphorus contents. *Leonotis* was found to conserve 84% soil, 50% water, 71% nitrogen and total 63% phosphorus. This was followed by *C. tora* showing 69%, 34%, *A. conyzoides* 57% and 44%, *P. hysterophorus* 45% and 25% and least *S. acuta* 33% and 19% respectively for soil and water CV. The nutrient conservation is both by the soil particles (surface adsorption) and dissolution in water. A detailed investigation was made for relative roles of the number of terminal rootlets per unit area of soil (4.67 x 10^5 m^2), canopy cover (98%), litter mass (46 g/m^{-2}), standing crop dry biomass (196 g /m^{-2}) and soil moisture level (12%). Their relative contributions in the total con-

servation were computed[26]. Canopy cover intercepts the beating energy of rain drops and the litter mass provides the cushioning effect. Fine to very fine roots effectively hold the soil at its place.

Other Cases

Klopatek[27] has found ecotones of forested wetlands as an extremely open system of inflow and outflow. The tree stands of *Taxodium, Acer, Ulmus, Fraxinus* and *Quercus* are reported[28] to provide stability to riparian ecotones by cutting down to river surface water flow. Their cover also provides suitable niche to diverse fauna. In nature, there is a constant struggle between the natural forces of erosion on ecotones and the vegetal cover to reduce it. It is only when man interferes, the ecotones lose this battle of habitat stabilization. Groeneveld and Griepentrog[29] have found that scraping of herbage cover greatly accelerates soil erosion and water runoff in their studies of Carnel River ecotone of California. They found that despite effective binding by roots of *Salix, Populus, Platanus* and *Alnus*, in certain years erosion events have been significant. In a Minnesota peatland watershed it has been reported[30] that upto 60% of the nutrients flowing down to streams is filtered by the vegetation. In riparian forestry of Maryland the nitrogen taken by trees was reported[31] as high as almost 90%. Thus the rivers and streams escape eutrophication because of ecotone vegetation. Kadlec and Kadlec[32] have regarded ecotones as the nature's "treatment system".

Acknowledgements

RSA is thankful to Banaras Hindu University for facilities as Professor Emeritus and NKA is thankful to Dr. Vijay Kumar, Head of Botany Department and Dr. Parvez E. Deen, Principal, Christ Church College, Kanpur for laboratory facilites.

References

1. Ambasht RS. Wetland Ecology,an overview. *Proc National Acad Sci India* 2008; **78** : sp. Issue pp. 3-12.
2. Ambasht RS, Ambasht NK. A Text Book of Plant Ecology. 15th edition, New Delhi : CBS Publ, 2008.
3. Clements FE. Research Methods in Ecology, Nebraska: University Publ. Co, 1905.
4. Odum EP. Basic Ecology. New York : Saunders College Publ, 1983.
5. Clements FE. Plant succession, an analysis of development of vegetation. Washington : Carnegie Institute. 1916.
6. Braun-Blanquet J. Pflanzensociologie. Vienna: Springer Verlag, 1951.
7. Daubenmire RF. Vegetation identification of typical communities. *Science* 1966; **151** : 291-298.
8. Gleason HA. The individualistic concept of the plant association. *Bull Torrey Botanical Club* 1926; **53** : 7-26.
9. Whittaker RH. A criticism of the plant association and climatic climax concepts. *Northwest Science* 1951; **25** : 17-31.
10. Whittaker RH. Gradient analysis of vegetation. *Biol Rev* 1967; **42** : 207-264.
11. Goodall DW. The continuum and individuals in-situ association. *Vegetatio*. 1963 **11** : 297-316.
12. Tiner RW. Wetlands are ecotones: reality or myth. In: Gopal B, Ilkowska AH, Wetzel RG, editors. Wetlands and Ecotones. New Delhi : Internat Sci Publ, 1993. pp 1-15.
13. Misra, R. A study of the ecology of low lying lands. *Indian Ecologist* 1946; **1** : 27-46.
14. Ambasht RS, Ram K. Stratified primary productive structure of macrophytic weeds in a large lake. In: Varshney CK, Rzoska J. editors. Aquatic Weeds of S.E. Asia. The Hague: W. Junk and Co, 1976. pp 147-155.
15. Ambasht RS. Macrophytes. In: Zafar AR, Khanum A, Mohan KS, editors. Limnology in the Indian subcontinent. Hyderabad: Ukas Pub, 2004; 158-174.
16. Chabreck RA. Coastal Marshes Ecology and Management. Minneapolis: University of Minnesota Press, 1988.
17. Tiner RW (Jr.) A field guide to coastal wetland plants of the Northeastern United States. Amherst: Univ. Massachusetts Press. 1987. pp 1-285.
18. Ambasht RS. Impact analysis of anthropogenic activities on productivity, soil erosion, eutrophication and sedimentation of Surhatal (Ballia) lake and surrounding wetlands and habitat restoration. Final Tech. Report. Ministry of Environment and Forest Project 1998, pp. 1-79.
19. Ambasht RS. Root habits in response to soil erosion, silting and inundation. PhD. Thesis, Banaras Hindu University, Varanasi, 1962.
20. Ambahst RS. Conservation of soil through plant cover of certain alluvial slopes in India. Gland: Proc. IUCN XI Tech. Meetings, 1970. pp 44-48.
21. Ambasht RS. Plant diversity, productivity and conservation studies of wetlands and their marginal ecotones. Final Tech. Report: CSIR Emeritus Scientist Scheme Project P. 25/185 1-15 BHU Varanasi/New Delhi. 2001.

22. Ambasht RS, Ambasht NK. Conservation of soil and nutrients through plant cover on wetland margins. In: Ambasht RS, Ambasht Navin K, editors: Modern Trends in Applied Aquatic Ecology. New York: Kluwer Acad Plenum Publ, 2003. pp 169-279.

23. Ambasht RS, Ambasht Navin K. Conservation of wetlands-Global and Indian perspectives. In: Kandya AK, Gupta A, editors. Advancing Frontiers of Ecologcal Researches in India, Dehradun; Bishen Singh Mahendra Pal Singh. 2006. pp. 247-257.

24. Kumar R, Ambasht RS, Srivastava NK. Conservation efficiency of fire Common riparian weeds in movement of soil, water and phosphorus. *J Applied Ecology* 1992; **29** : 737-744.

25. Kumar R, Ambasht RS, Srivastava NK. Nitrogen conservation efficiency of five common riparian weeds in runoff experiment on slopes. *J Environmental Management* 1992; **34** : 47-57.

26. Kumar R, Ambasht RS, Srivastawa AK, Srivastava NK, Sinha A. Reduction of nitrogen losses through erosion by *Leonotis nepetifolia* and *Sida acuta* in simulated rain intensities. *Ecological Engineering* 1997; **8** : 233-239.

27. Klopatek JM. The role of emergent marcophytes in mineral cycling in fresh water marsh. In: Howel FG, Gentry JB, Smith MH, editors. Mineral Cycling in south eastern ecosytems. Washington DC: Energy Research Development Administration, ERDA CONF 740513, 1975. pp. 367-393.

28. Brinson MM, Swift BL, Pantico RC, Barclay JS. Riparian Ecosystems. Their Ecology and status. Washington DC: U.S. Fish Wildlife Serv. FWS/0BS-81/17, 1981.

29. Groeneveld DP, Griepentrog TE. Inter-dependence of groundwater, riparian vegetation and streambank stability: A case study. In: USDA Forest Service (Tech. Report no RM 120). Riparian Ecosystems and their Management Fort Collins: 1985. pp 44-48.

30. Verry ES, Timmons DR. Water borne nutrient flow through an upland peatland watershed in Minnesota. *Ecology* 1982; **63** : 1456-1467.

31. Peterjohn WT, Correll DL. Nutrient dynamics in agricultural watershed: Observations on the role of riparian forests. *Ecology* 1984; **65** : 1466-1475.

32. Kadlec RH, Kadlec JA. Wetlands and water quality. In: Greeson PE, Clark JR, Clark JE, editors. Wetland Foundations and Values: The state of our understanding. Minneapolis: American Water Assoc, 1979. pp 436-456.

Proc. Nat. Acad. Sci. India, Sect. B, Vol. 78, Spl. Issue, 2008

Effects of UV-B radiation on phytoplankton and macroalgae : Adaptation strategies

R.P. SINHA**, S.P. SINGH and D.-P. HÄDER*

Centre of Advanced Study in Botany, Banaras Hindu University, Varanasi-221005, India.

**Department for Biology, Friedrich-Alexander University, Staudtstr.-5, D-91058, Erlangen, Germany.*

***e-mail : r.p.sinha@gmx.net*

Abstract

Recent results continue to indicate ozone depletion-related increases in solar ultraviolet-B radiation (UV-B; 280 - 315 nm) reaching the Earth's surface. Harmful doses of UV-B radiation can penetrate deep (up to several dozen meters) into the water column and may thus affect aquatic ecosystems. Aquatic ecosystems are key components of the Earth's biosphere since they produce more than 50 % of the biomass on our planet. Phytoplankton and macroalgae are the major biomass producers and form the basis of the aquatic food webs. The highly energetic UV-B has the greatest potential for cell damage caused by both direct effects on DNA and proteins and indirect effects *via* the production of reactive oxygen species. UV-B can cause wide ranging damage such as reduction in development and reproduction resulting in loss of productivity of phytoplankton and macroalgae. Consequences of loss of productivity are reduced sink capacity for atmospheric CO_2 and negative effects on species diversity, ecosystem stability, trophic interactions and ultimately biogeochemical cycles. However, a number of species have developed various adaptation strategies to counteract the damaging effects of UV-B. These strategies include vertical migration within the water column, repair of DNA damage and production of UV-absorbing/screening mycosporine-like amino acids (MAAs). This article deals with the effects of UV-B radiation on phytoplankton and macroalgae and the adaptation strategies applied by them to reduce the negative effects of UV-B.

Key words: adaptation, macroalgae, mycosporine-like amino acids (MAAs), phytoplankton, UV radiation

सारांश

हाल के लगातार अध्ययन यह दर्शाते है कि ओजोन क्षय के कारण पृथ्वी की सतह पर पराबैगनी–बी विकिरण (280 - 315 नैनोमीटर) की वृद्धि हुई है। हानिकारक पराबैगनी–बी विकिरण जल के गहरे स्तम्भ (कई दर्जन मीटर तक) को भेद सकती है और इस प्रकार जलीय परिस्थितिकी तन्त्र को प्रभावित कर सकती है। जलीय पारिस्थितिकी तन्त्र पृथ्वी के जैवमडल के प्रमुख घटक है क्योकि ये हमारे ग्रह के कुल जैवभार का 50% से भी अधिक उत्पादित करते है। पादप प्लवक और उच्च शैवाल प्रमुख जैवभार उत्पादक है तथा जलीय खाद्य जाल के आधार का निर्माण करते हैं। अति ऊर्जान्वित पराबैगनी–बी विकिरण सीधे डीएनए और प्रोटीन को प्रभावित कर या प्रतिक्रियाशील ऑक्सीजन स्पीसीज के उत्पादन के द्वारा कोशिकाओं को नष्ट करने मे अति सक्षम है। पराबैगनी–बी विकिरण विकास एव प्रजनन मे कमी करके पादप प्लवक तथा उच्च शैवाल की उत्पादकता मे ह्रास जैसे वृहत हानिकारक प्रभाव उत्पन्न कर सकती है। उत्पादकता मे कमी के परिणामस्वरूप वायुमंडलीय कार्बन डाई ऑक्साइड के उपयोग मे ह्रास और जातीय विविधता, पारिस्थितिकी तन्त्र का स्थायित्व, पोष अन्योन्यक्रिया तथा अंतत जैव भू–रासायनिक चक्र पर नकारात्मक प्रभाव पड सकता है। यद्यपि कई प्रजातियो ने पराबैगनी–बी विकिरण के हानिकारक प्रभाव को कम करने के लिये कुछ विशिष्ट अनुकूलनीय रणनीति विकसित किया है। इन रणनीतियो मे जल स्तम्भ में क्षैतिज गमन, क्षतिग्रस्त डीएनए की मरम्मत करना तथा पराबैंगनी–बी विकिरण रक्षावरण या अवशोषक मायकोस्पोरिन सदृश अमीनो अम्लो का उत्पादन सम्मिलित है। यह अभिलेख पादपप्लवक व उच्च शैवाल पर पराबैंगनी–बी विकिरण के प्रभाव तथा उनके द्वारा पराबैगनी–बी विकिरण के नकारात्मक प्रभावो को कम करने के लिये प्रयुक्त रणनीति पर प्रकाश डालता है।

सांकेतिक शब्द : अनुकूलन, गुरूशैवाल, मायकोरपोरिन सदृश अमीनो अम्ल, पादप प्लवक, परा बैगनी विकिरण

Introduction

Continued depletion of stratospheric ozone layer due to anthropogenic released atmospheric pollutants such as chlorofluorocarbons (CFCs), chlorocarbons (CCs) and organobromides (OBs) has resulted in an increase in UV-B (280 - 315 nm) radiation on the earth's surface[1,2]. Ozone depletion has been reported in both Antarctic and Arctic regions, where ozone layers have been reported to decline by more than 70 % during late winter and early spring due to a phenomenon known as polar vortex[3-5].

Solar radiation is the primary source of energy for photosynthesis that drives almost all life forms on earth. However, short wavelength solar radiation,

particularly UV-B, can have deleterious effects on various organisms including phytoplankton and macroalgae[6]. Incident solar radiation at the surface and the depth of penetration into the water column are the decisive factors controlling photodamage to aquatic photosynthetic organisms[7]. Aquatic ecosystems differ substantially in their transparency and thus the depth of solar penetration[8-10]. Inorganic particulate substances, dissolved and particulate organic carbon (DOC and POC), humic substances, and suspended organisms are the main absorbers of short wavelength solar radiation[11].

Phytoplankton and other pelagic organisms can move freely in the water column by active swimming or changing their buoyancy. In open oceanic waters, vertical migration is superimposed by the action of waves and wind[12]. Therefore, the impact of solar radiation is modified by the depth and rate of the mixing layer[13]. In contrast to phytoplankton, most macroalgae are sessile and therefore restricted to their growth site[14]. Macroalgae show a distinct pattern of vertical distribution in their habitat that is mainly controlled by light penetration[15-17]. Macroalgae are economically important as they are being exploited for food production, as fertilizers, and as raw materials for getting substances such as agar and carragheenan[14,18].

Studies have revealed that UV-B can severely harm phytoplankton and macroalgae by reducing photosynthesis and growth rates[19,20], damaging DNA through the formation of cyclobutane pyrimidine dimers or pyrimidine (6-4) pyrimidone photoproducts[21-23], degrading proteins[24], forming reactive oxygen species[25] and impairing motility and vertical migration[26]. However, a number of organisms have evolved mechanisms such as vertical migration in the water column[20], repair of DNA damage[27,28] and synthesis of UV-protectant mycosporine-like amino acids (MAAs)[29-32]. The paper discusses some of the UV-B-mediated effects on phytoplankton and macroalgae and their adaptation strategies to withstand the damaging effects of UV-B radiation.

Effects of UV-B on Phytoplankton

Phytoplankton organisms are the basis of marine food webs and thus indirectly contribute to human nutrition. They also play an important role in the regulation of global climate. It has been estimated that about 50% of the total carbon fixation is attributed to marine ecosystems with most of it due to phytoplankton organisms[6]. In addition to the contribution of phytoplankton to carbon fixation, there are specific effects of phytoplankton on climate. Some phytoplankton genera produce volatile substances, mainly dimethyl sulfide (DMS), providing a cooling effect on the atmosphere, since they are precursors of cloud condensation nuclei. The cumulative effects of marine biota in the uptake of atmospheric CO_2 and emission of DMS have been estimated to cool the atmosphere by up to 6°C[33].

The distribution of phytoplankton is not uniform in the oceans. The dependence on solar radiation as the primary source of energy restricts phytoplankton to depths at which the penetration of light supports photosynthesis. This range is defined as the euphotic zone. The horizontal distribution of phytoplankton is also highly variable. In large regions of the oceans a stable boundary exists between nutrient-rich deep sea water and nutrient-poor surface water. Thus, the accumulation of phytoplankton biomass is limited by nutrient availability. Regions near the coast and at higher latitudes contain more phytoplankton biomass because of higher nutrient availability due to upwelling of nutrient-rich water from the deep sea and terrestrial influxes. Especially the southern ocean is highly productive[34-37].

The life of phytoplankton depends on solar radiation that provides energy used via the photosynthetic process. Simultaneously, excessive UV-B radiation damages diverse targets within the organism. Inhibition of photosynthesis and growth, DNA damage and finally cell death are among the common effects of UV-B on phytoplankton. High levels of visible radiation induce the formation of active oxygen species that affect cell integrity. UV-B reduces the content of photosynthetic pigments in phytoplankton and leads to lower photosynthetic rates[38,39]. Apart from the photosynthetic pigments a major target of UV damage is the electron transport chain of photosystem II[40]. Functional relationships between the wavelength of radiation and the photoinhibition of photosynthesis (biological weighing functions, BWFs) have been determined experimentally[41-44]. The inhibitory effect of UV radiation increases exponentially with decreasing wavelength in the UV-A and the UV-B portion of the spectrum. However, due to its higher proportion in the solar spectrum, the inhibitory effect of UV-A radiation has been estimated to be higher than the UV-B effect, in some cases even for the conditions of ozone

depletion[41,45]. The shape of a BWF may be strongly influenced by the physiological state of the organisms, e.g. the induction of tolerance mechanisms. For example, the inhibitory effect of UV radiation in the wavelength range of MAA absorption can be greatly diminished if high concentrations of these UV-absorbing compounds are present in the organisms[46].

The peak absorption of DNA lies in the UV-C range that is absorbed in the upper layers of the atmosphere and does not reach the ozone layer. However, the absorption of UV-B radiation by DNA is sufficient to induce severe damage to the DNA of phytoplankton. Absorbed quanta of UV can induce changes in the molecular structure of the DNA[22,47,48]. The main effect of UV-B radiation is the formation of dimers between two adjacent pyrimidine bases, cis-syn cyclobutan dimers and pyrimidine (6-4) pyrimidone photoproducts. These DNA lesions interfere with DNA transcription and replication and can lead to misreading of the genetic code causing mutations and death. There are big differences in the susceptibility of phytoplankton species to DNA damage that seem to be correlated with cell size and shape. Taking into account that DNA is among the main lethal targets of UV-B radiation, the susceptibility of a species to UV-B-induced DNA damage is a good indicator of overall UV-B sensitivity[49].

Investigations of the effects of ozone depletion on phytoplankton productivity in the southern ocean, where the increase in UV-B radiation is most pronounced, show large differences. A reduction in primary production of 6-12 % in the marginal ice zone of the Bellingshausen sea has been estimated[3]. Another study, simulating the effect on aquatic primary production using model-derived radiation conditions and BWFs, only found a reduction of less than 1% integrated over the southern ocean[45]. The large difference between the estimates reflects the complexity of large-scale estimates on UV-B effects. A differential impact of UV-B radiation may be partially a result of interactions with other factors, such as the extent of vertical mixing. By vertical mixing organisms from deeper levels are brought to the surface where they become photoinhibited while inhibited organisms from near surface are transported to deeper levels where availability of light becomes limiting. Thus, the overall decrease in photosynthesis becomes larger[7,20,46]. In addition, solar radiation and UV-B radiation are known to inhibit the ability of phytoplankton to move and orient within the water column[26,50,51].

Adaptation strategies in Phytoplankton

The recent effects of UV-B are not new phenomena but have accompanied the whole evolutionary process of phytoplankton. Therefore, phytoplankton organisms have developed certain tolerance mechanisms to avoid harmful UV radiation. These include (a) vertical migration within the water column to avoid exposure to excessive doses of harmful radiation. Many species of phytoplankton actively move up and down in the water column, controlled by gravitactic and phototactic orientation[52]. This mechanism allows the organisms to adjust the impinging radiation to a level that is suitable for photosynthesis and to avoid excess doses of visible as well as UV radiation[50,52].

(b) repair of DNA damage[49]. There are three mechanisms known that can repair damaged portions of DNA: (i) photoenzymatic repair (PER) that involves the enzyme DNA photolyase that monomerizes cyclobutane dimers in the presence of visible or UV-A light, (ii) nucleotide excision repair (NER) has a broader spectrum of action and involves the recognition of damaged DNA portions and the excision and resynthesis of the damaged strand by DNA polymerase, and (iii) recombinational repair (post replication repair) may resolve DNA damage that has been bypassed by the replication machinery[27,28,49]. The capacity and kinetics of DNA repair differ greatly between phytoplankton species. This includes different relative importance of either PER and NER. The removal of cyclobutane dimers by PER, in the presence of PAR or UV-A radiation, may enhance the light-independent NER of other DNA lesions[48,49], and

(c) the production of UV-absorbing/screening, mycosporine-like amino acids (MAAs)[29,53-59].

Several phytoplanktons from different regions and taxonomic groups have been found to contain MAAs. Most of the research has focused on marine phytoplankton, but there are a few reports on the occurrence of MAAs in freshwater algae[60] also. So far MAAs have been reported to occur predominantly in species of the Dinophyceae, Bacillariophyceae and Haptophyceae. In addition to the reports from experiments with phytoplankton in culture, there are numerous reports on UV-absorbing properties of ocean waters that are assumed to be caused by the presence of MAAs[61]. A UV-absorbing compound was found in a phytoplankton bloom in the Icelandic basin, which

showed an absorption spectrum and chromatographic behavior similar but not identical to scytonemin. However, this pigment has not yet been chemically characterized, and therefore, there is no evidence for the presence of scytonemin or similar pigments in phytoplankton organisms[62].

Besides MAAs, sporopollenin, a biopolymer of variable chemical composition, has been proposed to play a possible role in screening UV radiation in some freshwater phytoplankton species[58]. The assumption that MAAs act as protectants against UV radiation has been derived from the fact that the distribution of MAAs in marine organisms often shows a correlation with depth and thus with the dosage of UV or PAR radiation[63]. In some phytoplankton species the accumulation of MAAs is induced by UV radiation[53,54] which supports the theoretical assumption that the presence of UV-absorbing compounds provides screening to the constituents of a cell[64]. Direct evidence for their protective function in phytoplankton has been demonstrated where high amounts of intracellular MAAs diminish the inhibitory effect of UV radiation on photosynthesis[25,46]. The accumulation of MAAs also protects microalgae from inhibition of motility by UV-B radiation[59].

The effectivity of screening by UV-absorbing compounds largely depends on cell size. Due to the longer optical path length internal sunscreens are more effective in large cells. However, smaller cells may increase the effectivity of screening by forming dense populations that provide mutual shading from deleterious UV-B radiation. However, in this case it is doubtful that the presence of UV-screening substances will provide a competitive advantage to the cells producing them since other species may also benefit from the screening of UV radiation[64]. The same applies to cases in which the UV-absorbing substances are released to the surrounding medium as in the dinoflagellate *Lingulodinium polyedra*[57]. The synthesis of MAAs is strongly influenced by radiation intensity as well as by the spectral composition. In the dinoflagellate *Alexandrium excavatum* isolated from the continental shelf near Buenos Aires, the transfer from low (20 $\mu E\ m^{-2}\ s^{-1}$) to high (200 $\mu E\ m^{-2}\ s^{-1}$) PAR led to a change in MAA composition and an overall increase in UV absorption within a few hours[53,65]. Accumulation of MAAs in this organism also depends on the spectral composition of the light; blue light is more effective than green and red light, and UV-A radiation strongly enhances MAA accumulation[53]. Exposure to sunlight leads to a strong increase of MAA content in *Alexandrium excavatum*[54]. In the dinoflagellate *Prorocentrum micans*, after 21 days of growth in the presence of UV radiation, the organisms contained higher concentrations of MAAs in comparison to those

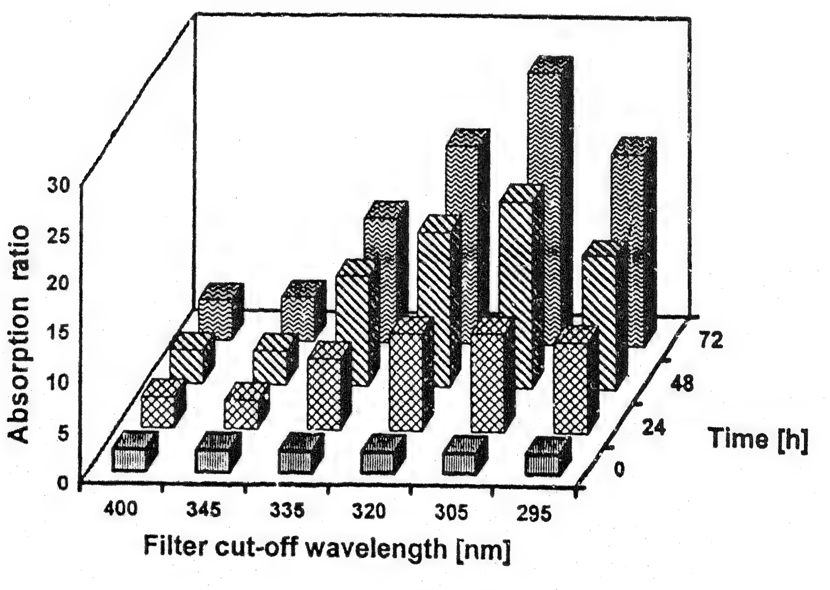


Fig. 1 - The ratio of MAAs peak absorption (from 325 to 337 nm) to Chl *a* absorption (665 nm) in methanolic extracts from *Gyrodinium dorsum* exposed to simulated solar radiation under various cut-off filters for indicated time periods.

grown in the absence of UV radiation[25]. The ubiquitous haptophyte species, *Phaeocystis pouchetii*, contains UV-absorbing compounds only in the colonial stage of its life cycle, and the concentration has been found to be higher in isolates from the Antarctic region than in isolates from temperate regions[66].

In long-term experiments with natural Antarctic phytoplankton assemblages MAA concentrations have been shown to increase after exposure to PAR with UV but not to PAR without UV[67]. The spectral effect of radiation on MAA synthesis differs largely between species. In *Phaeocystis antarctica* the induction of MAA synthesis is induced predominantly by short wavelength UV-A but also by UV-B radiation, while some diatom species respond predominantly to long wavelength UV-A and short wavelength visible radiation[68]. In the dinoflagellate *Gyrodinium dorsum* the accumulation of MAAs is stimulated by PAR and UV radiation (Fig. 1), but the most prominent induction is caused by radiation below 345 nm[69]. A polychromatic action spectrum for the synthesis of MAA

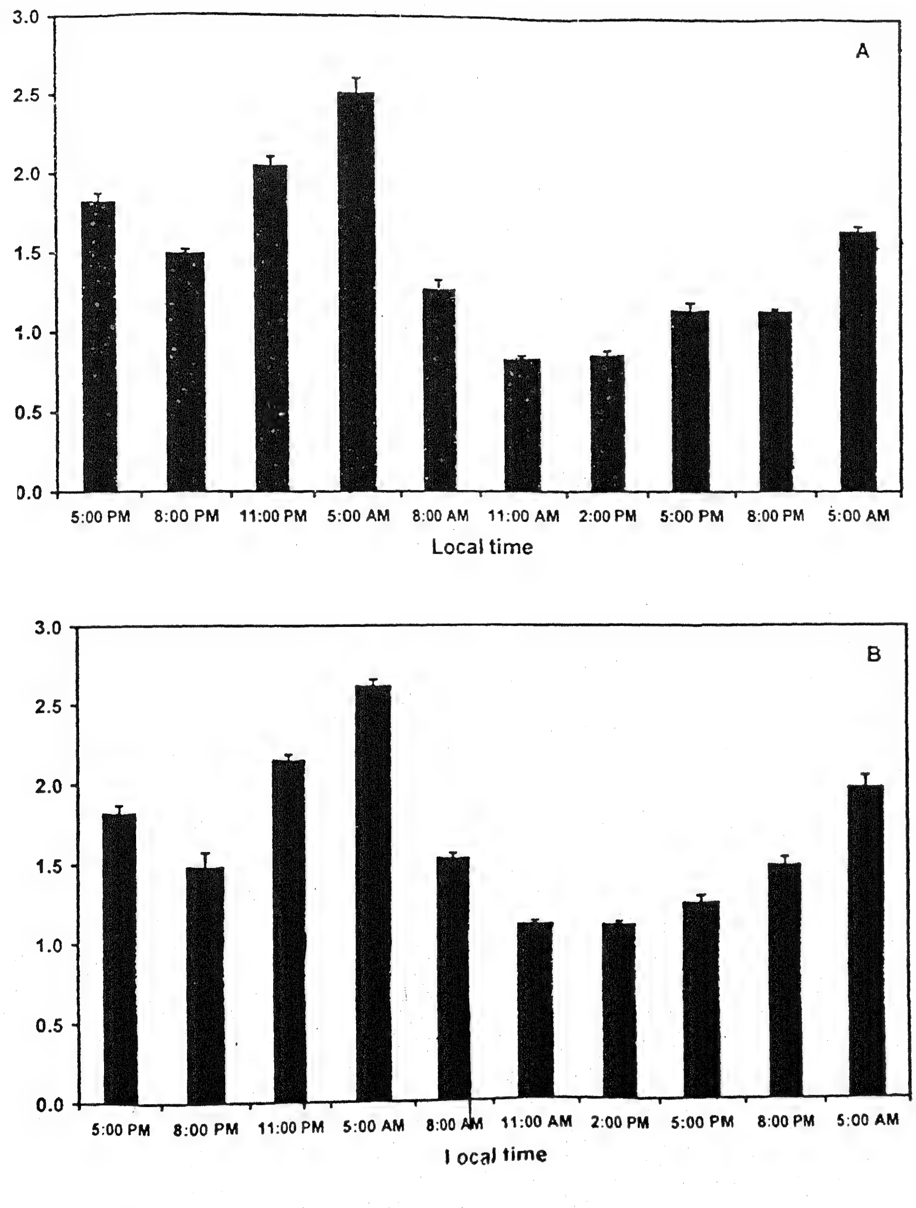


Fig. 2 - Degradation and resynthesis of phycoerythrin (PE) in *Callithamnion* over a period of 36 h alternating dark and light cycle under complete solar radiation (A) or only the PAR component (B) of solar radiation (under a 395 nm cut-off filter).

in *Gyrodinium dorsum* shows a pronounced peak at around 310 nm in the UV-B range[70]. So, it is evident that production of MAAs is one of the strategies by which phytoplankton may withstand harmful radiation[39,71].

Effects of UV-B on Macroalgae

Coastal areas all over the world are inhabited by macroalgae[72]. Since macroalgae grow in supralittoral to sublittoral zones they are exposed to varying levels of solar radiation. The absorption of solar radiation in the water column begins in the lower wavelength bands. Algae growing in the supralittoral or the eulittoral zones are exposed to solar radiation including UV, while algae growing in the sublittoral zones are exposed mainly to PAR. Many algae show a distinct zonation at their growing site[73-75]. The influence of increasing solar radiation affects the macroalgae directly and indirectly. Direct influence is the damage of DNA[76], pigment composition and the photosynthetic apparatus[77]. The indirect effect can be caused by changes in the environment of the algae like desiccation, changes in temperature and the release of toxic substances by the influence of UV irradiation on chemicals in the water.

In their natural environment photoinhibition depends on the growth site of the algae. Macroalgae growing at the surface or in the intertidal zone show much higher photoinhibition compared to macroalgae growing in the subtidal zone or in crevices[7,78]. In the field, as well as under laboratory conditions, the influence of UV-B radiation on photosynthetic quantum yield, oxygen evolution and respiration as well as the recovery has been investigated by several workers[12,17,79-82]. Algae growing in transparent waters show a higher photoinhibition than algae growing in turbid waters[79]. A reduced photosynthetic activity of algae around midday was shown in the field as well as under laboratory conditions[12,78]. Depending on the stage in their life cycle different photoinhibition and recovery levels were found in *Laminaria saccharina* being maximal in the young gametophytes[83]. Laboratory studies of *Dasycladus vermicularis* exposed to PAR with or without UV radiation led to a complete loss in oxygen evolution after 24 h of PAR + UV-A + UV-B radiation[80]. In *Mastocarpus stellatus* a drastic

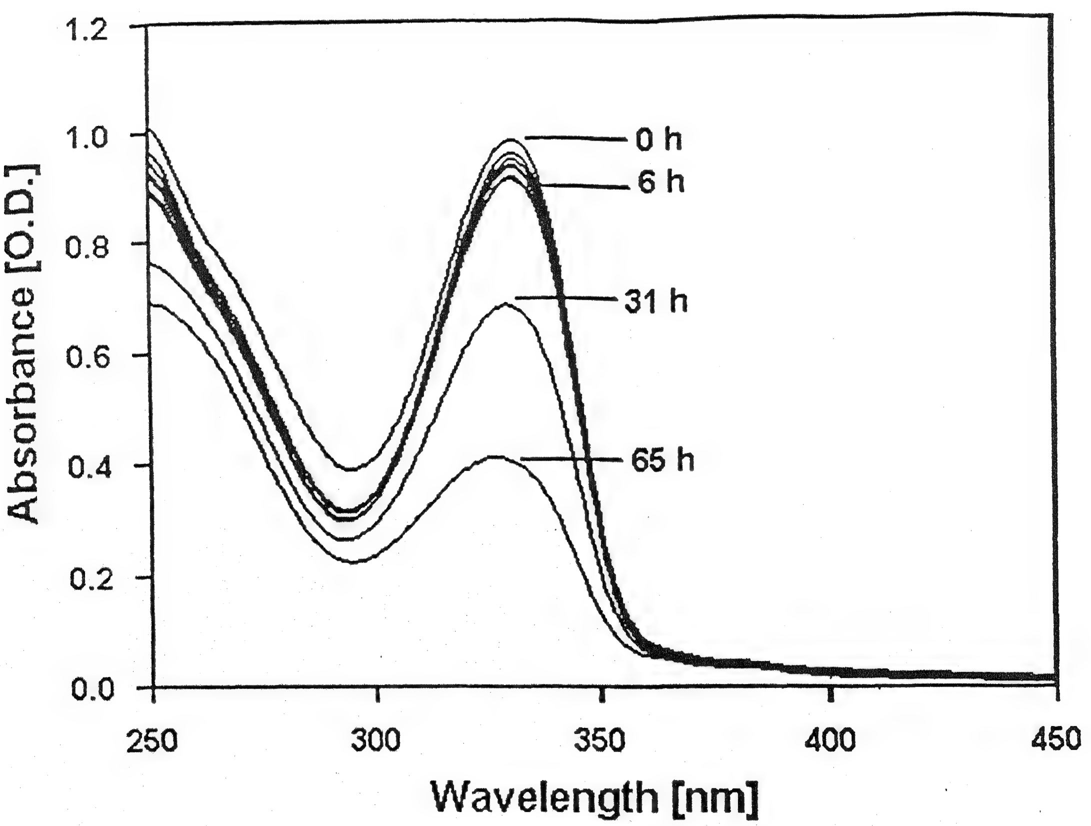


Fig. 3 - Absorption spectra of the MAAs of *Gracilaria cornea* after increasing exposure time to UV-B.

decline in the ratio of the photosynthetic quantum yield was shown when the thalli were exposed for 3 days to a solar simulator[39]. The decrease is mainly caused by PAR while the effect of additional UV-A or UV-B does not affect the algae as drastically as that of PAR. The algae show a recovery up to about 50 % for PAR with or without UV-A, while the thalli irradiated with PAR + UV-A + UV-B recover only to 40%[81].

The pigment content in macroalgae depends on the radiation level and differs between sun and shade type algae[84]. The pigment turn-over is known to be governed by a diurnal rhythm[85,86]. Changes in specific pigment content were monitored in three marine red algae e.g., *Callithamnion byssoides* (Fig. 2), *Ceramium rubrum* and *Corallina officinalis* over a period of 36 h during alternating light/dark cycles under total solar radiation (without filter) or only the PAR component of solar radiation (under a 395 nm cut-off filter). There was a decline in the amount of accessory light harvesting pigments such as phycocyanin and phycoerythrin during light periods and an increase during dark periods in all the red algae showing a circadian rhythm of phycobiliproteins destruction and resynthesis[86]. These daily patterns indicate a rapid turnover of the pigments in the natural environment of algae[87].

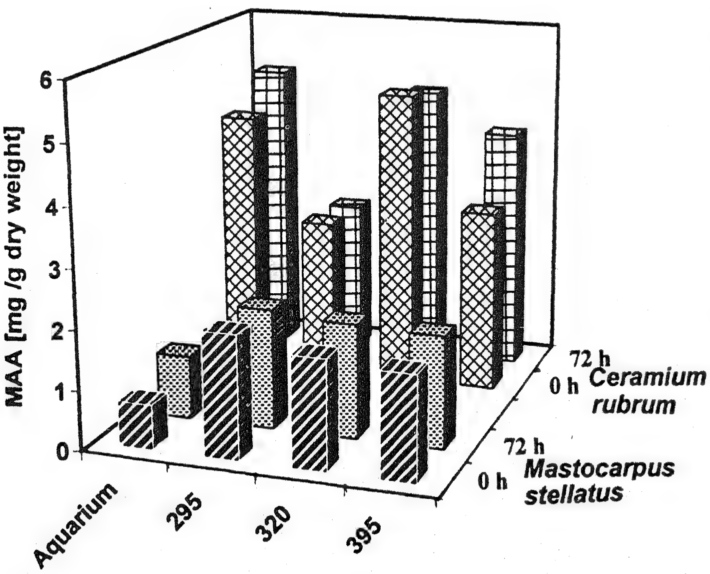


Fig. 4 - MAAs contents in *Mastocarpus stellatus* and *Ceramium rubrum* after 72 h of exposure (12/12 h light/dark cycle) to indicated irradiation conditions.

Adaptation strategies in macroalgae

The decrease in PS II efficiency and photosynthetic capacity can be regarded as an active adaptation to the changing irradiation conditions[88]. The phenomenon has been seen in algae from the tropics and mid latitudes as well as in Arctic and Antarctic macroalgae[15,88,89]. The regulatory mechanisms designed to ameliorate light stress include thermal dissipation of excess excitation energy, antioxidant systems, chloroplast movements, adjustment of the antenna size, and the fast repair of photooxidative damage[7,90].

Another efficient adaptation strategy applied by macroalgae is to synthesize a number of UV-absorbing/screening substances such as carotenoids and MAAs[29,91]. MAAs in macroalgae were first reported in 1961[92]. In the last few years qualitative and quantitative studies were carried out to survey the distribution of MAAs among macroalgae. MAAs are distributed in macroalgae from polar to tropical habitats[29,93]. Presence of MAAs in macroalgae has been reported from the Antarctic[94] region also. A survey of Rhodophyta, Phaeophyta and Chlorophyta from tropical to polar habitats gives a broad overview of the distribution of MAAs in macroalgae[29,93,95]. The percentage of investigated species containing MAAs is much higher in red algae than in brown and green algae. Both the number of different MAAs as well as the total amount of MAAs is higher in Rhodophyta compared to Phaeophyta or Chlorophyta. A decreasing amount of MAAs is found with increasing depth in the water column as well as in species from higher latitudes. Deep-water (more than 2 m; depending on water turbidity) algal species do not contain MAAs[96]. Therefore, the MAA content in algae varies between classes and with increasing depths. Differential results in MAA analysis are also influenced by exposure to solar radiation[97].

Basically three patterns of MAA distribution are found among macroalgae; (a) high initial MAA content and no increase during light treatment, (b) low MAA content with an increase during light treatment, and (c) no initial MAA and no induction during light treatment. Initial high levels but no significant increase in the MAA content was found in the upper intertidal Rhodophyta, *Porphyra umbilicalis*[81]. Similarly, no *in vivo* induction of MAAs was recorded after exposure to either UV alone or in combination with PAR in the marine red alga, *Gracilaria cornea*, which pos-

sesses a very high amount of naturally occurring MAAs having an absorption maximum at 334 nm. The MAAs were highly stable against UV-B irradiation (Fig. 3) and heat treatment[98]. In the Chlorophyta *Dasycladus vermicularis* UV-absorbing substances were found, but their absorption spectra and retention times did not resemble those of known MAAs[80].

The intertidal Rhodophytes *Mastocarpus stellatus* and *Ceramium rubrum* were exposed to a solar simulator using different cut-off filters to produce PAR only or PAR + UV-A or PAR + UV-A + UV-B. Small changes in the MAA content (Fig. 4) were observed in both algae[39]. As both algae were collected from the intertidal zone in Helgoland in July 1998 their initial content of MAAs at the beginning of the experiment might have been sufficient for protection to solar radiation or the maximum accumulation for these species had already been reached. In *Polyides rotundus*, exposed under the same conditions, no initial MAAs were found and no MAAs were induced during the experiment. A polychromatic action spectrum for the induction of MAAs in the Chlorophyte *Prasiola stipitata* shows a clear maximum at 300 nm[99]. In the red alga *Chondrus crispus* blue and UV-A radiation induces the synthesis of MAAs; however, the induction by UV-B was not investigated[100]. A database on MAAs in various organisms is available at http://www.biologie.uni-erlangen.de/botanik1/html/eng/maa_database.htm[29].

Conclusion

Increase in the level of UV-B radiation are likely to induce changes in community structure since there are great differences in susceptibility of species to UV-induced damage. Species with larger cells, having the ability to accumulate UV-screening substances or with more effective repair mechanisms will likely be favored. There is ample evidence that the change in the radiation climate originating from the depletion in stratospheric ozone has significant adverse effects on wetland organisms. However, the adaptation strategies of organisms partially mitigate the inhibitory effects of UV-B. Differential sensitivity of species and the subsequent changes in community structures may lead t(changes in steady-state conditions that still sustain :. high primary production. Changes in species composition might have consequences propagating within aquatic food webs that are at present difficult to predict. The ecological significance of photoprotective compounds in diverse organisms as screening agents against UV-induced damage has yet to be elucidated. Not much is known about the spatial distribution of MAAs within the cells. The reports on specific distributions of absorption due to MAAs in the water column indicate a role of these compounds in protection against UV radiation. A literature survey reveals that MAAs may serve at least three different functions: (a) they may protect the cells from UV photodamage by playing a sunscreen role, (b) they may function as antioxidants, and (c) they may aid in osmotic regulation. Thus, irrespective of the fact that UV protective compounds show a primary or secondary function or that they are synthesized due to UV radiation, the presence of these compounds in an organism may provide protection to the internal organelles and components from the full impact of deleterious UV radiation.

References

1. Crutzen PJ. Ultraviolet on the increase. *Nature* 1992; **356**: 104-105.

2. Kerr JB, McElroy CT. Evidence for large upward trends of ultraviolet-B radiation linked to ozone depletion. *Science* 1993; **262** : 1032-1034.

3. Smith RC, Prezelin BB, Baker KS, Bidigare RR, Boucher NP, Coley T, Karentz D, MacIntyre S, Matlick HA, Menzies D, Ondrusek M, Wan Z, Waters KJ. Ozone depletion: ultraviolet radiation and phytoplankton biology in Antarctic waters. *Science* 1992; **255** : 952-959.

4. Von der Gathen P, Rex M, Harris NRP, Lucic D, Knudsen BM, Braathen GO, De Backer H, Fabian R, Fast H, Gil M, Kyro E, Mikkelsen IS, Rummukainen M, Stähelin J, Varotsos C. Observational evidence for chemical ozone depletion over the Arctic in winter 1991-1992. *Nature* 1995; **375** : 131-134.

5. Farman JC, Gardiner BG, Shanklin JD. Large losses of total ozone in Antarctica reveal seasonal CLOx/NOx interaction. *Nature* 1985; **315** : 207-210.

6. Häder D:P, Kumar HD, Smith RC, Worrest RC. Effects of solar UV radiation on aquatic ecosystems and interactions with climate change. *Photochem Photobiol Sci* 2007; **6** : 267-285.

7. Häder D-P. Photoinhibition and UV response in the aquatic environment. In: Demmig-Adams B, Adams III WW, Mattoo AK, editors. Photoprotection, Photoinhibition, Gene regulation, and Environment. The Netherlands: Springer, 2006. pp. 87-105.

8. Laurion I, Ventura M, Catalan J, Psenner R, Sommaruga R. Attenuation of ultraviolet radiation in mountain lakes:

factors controlling the among- and within-lake variability. *Limnol Oceanogr* 2000; **45** : 1274-1288.

9. Conde D, Aubriot L, Sommaruga R. Changes UV penetration associated with marine intrusions and s. vater discharge in a shallow coa tal lagoon of the Southe Atlantic Ocean. *Mar Ecol Prog Ser* 2000; **207** : 19-31

10. Dring MG, Wagner A, Franklin LA, Kuhlenkamp R. ining K. Seasonal and diurnal variations in ultraviolet- and ultraviolet-A irradiances at and below the sea surfa e at Helgoland (North Sea) over a 6-year period. *Helgol Mar Res* 2001; **55** : 3-11.

11. Arts MT, Robarts RD, Kasai F, Waiser MJ, Tumber VP, Plante AJ, Rai H, de Lange HJ. The attenuation of ultraviolet radiation in high dissolved organic carbon waters of wetlands and lakes on the northern Great Plains. *Limnol Oceanogr* 2000; **45** : 292-299.

12. Häder D-P. Penetration and effects of solar UV-B on phytoplankton and macroalgae. *Plant Ecol* 1997; **128** : 4-13.

13. Huot Y, Jeffrey WH, Davis RF, Cullen JJ. Damage to DNA in bacterioplankton: a model of damage by ultraviolet radiation and its repair as influenced by vertical mixing. *Photochem Photobiol* 2000; **72** : 62-74.

14. Luning K. Seaweeds. Their environment, biogeography and ecophysiology. New York: Wiley, 1990.

15. Dring MJ, Wagner A, Boeskop J, Lüning K. Sensitivity of intertidal and subtidal red algae to UV-A and UV-B radiation, as monitored by chlorophyll fluorescence measurements: influence of collection, depth and season and length of irradiation. *Eur J Phycol* 1996; **31** : 293-302.

16. Hanelt D, Melcherttsmann B, Wiencke C, Nultsch W. Effects of high light stress on photosynthesis of polar macroalgae in relation to depth distribution. *Mar Ecol Prog Ser* 1997; **149** : 255-266.

17. Larkum AWD, Wood WF. The effect of UV-B radiation on photosynthesis and respiration of phytoplankton, benthic macroalgae and seagrasses. *Photosyn Res* 1993; **36** : 17-23.

18. Jensen A. Production of alginate. In: Wiessner W, Schnepf E, Starr RC, editors. Algae, Environment and Human Affairs. Bristol, England: Biopress Ltd, 1995. pp. 79-92.

19. Villafañe VE, Sundbäck K, Figueroa FL, Helbling EW, Photosynthesis in the aquatic environment as affected by UVR. In: Helbling EW, Zagarese HE, editors. UV Effects in Aquatic Organisms and Ecosystems. Cambridge: The Royal Society of Chemistry, 2003. pp. 357-397.

20. Richter P, Helbling W, Streb C, Häder D-P. PAR and UV effects on vertical migration and photosynthesis in *Euglena gracilis*. *Photochem Photobiol* 2007; **83** : 818-823.

21. Buma AGJ, Boelen P, Jeffrey WH. UVR-induced DNA damage in aquatic organisms. In: Helbling EW, Zagarese HE, editors. UV Effects in Aquatic Organisms and Ecosystems. Cambridge: The Royal Society of Chemistry, 2003. pp. 291-327.

22. Klisch M, Sinha RP, Helbling EW, Häder D-P. Induction of thymine dimers by solar radiation in natural freshwater phytoplankton assemblages in Patagonia, Argentina. *Aquat Sci* 2005; **67** : 72-78.

23. Sinha RP, Dautz M, Häder D-P. A simple and efficient method for the quantitative analysis of thymine dimers in cyanobacteria, phytoplankton and macroalgae. *Acta Protozool* 2001; **40** : 187-195.

24. Garde K, Gustavson K. The impact of UV-B radiation on alkaline phosphatase activity in phosphorus-depleted marine ecosystems. *J Exp Mar Biol Ecol* 1999; **238** : 93-105.

25. Lesser MP. Acclimation of phytoplankton to UV-B radiation: oxidative stress and photoinhibition of photosynthesis are not prevented by UV-absorbing compounds in the dinoflagellate *Prorocentrum micans*. *Mar Ecol Prog Ser* 1996; **132** : 287-297.

26. Richter P, Häder D-P, Gonçalves RJ, Marcoval MA, Villafañe VE, Helbling EW. Vertical migration and motility responses in three marine phytoplankton species exposed to solar radiation. *Photochem Photobiol* 2007; **83** : 810-817.

27. Sinha RP, Häder D-P. UV-induced DNA damage and repair: a review. *Photochem Photobiol* Sci 2002; **1** : 225-236.

28. Häder D-P, Sinha RP. Solar ultraviolet radiation-induced DNA damage in aquatic organisms: potential environmental impact. *Mut Res* 2005; **571** : 221-233.

29. Sinha RP, Singh SP, Häder D-P. Database on mycosporines and mycosporine-like amino acids (MAAs) in fungi, cyanobacteria, macroalgae, phytoplankton and animals. *J Photochem Photobiol B: Biol* 2007; **89** : 29-35.

30. Oren A, Gunde-Cimerman N. Mycosporines and mycosporine-like amino acids: UV protectants or multipurpose secondary metabolites? *FEMS Microbiol Lett* 2007; **269** : 1-10.

31. Bjorn LO. Stratospheric ozone, ultraviolet radiation, and cryptogams. *Biol Conservat* 2007; **135** : 326-333.

32. Xue L, Zhang Y, Zhang T, An L, Wang X. Effects of enhanced ultraviolet-B radiation on algae and cyanobacteria. *Crit Rev Microbiol* 2005; **31** : 79-89.

33. Watson AJ, Liss PS. Marine biological controls on climate via the carbon and sulphur geochemical cycles. *Phil Trans R Soc Lond* 1998; **353** : 41-51.

34. Valiela I. Marine Ecological Processes, second Edition, New York : Springer, 1995.

35. Bontempi PS, Yoder JA. Spatial variability in Sea WiFS Imagery of the Southern Atlantic bight as evidenced by gradients (fronts) in chlorophyll a and water-leaving radiance. *Deep Sea Res Part II* 2004; **51** : 1019-1032.

36. Stuart V, Ulloa O, Alarcón G, Sathyendranath S, Major H, Head EJH, Platt T. Bio-optical characteristics of phytoplankton populations in the upwelling system off the coast of *Chile Rev Chil Hist Nat* 2004; **77** : 87-105.

37. Tiera E, Mourino B, Maranón E, Pérez V, Paz MJ, Serret P, de Armas D, Escánez J, Woodward EMS, Fernández E. Variability of chlorophyll and primary production in the Eastern North Atlantic subtropical gyre: potential factors affecting phytoplankton activity. *Deep Sea Res Part I* 2005; **52** : 569-588.

38. Gerber S, Häder D-P. Effects of enhanced solar irradiance on chlorophyll fluorescence and photosynthetic oxygen production of five species of phytoplankton. *FEMS Microbiol Ecol* 1995; **16** : 33-42.

39. Sinha RP, Klisch M, Gröniger M, Häder D-P. Responses of aquatic algae and cyanobacteria to solar UV-B. *Plant Ecol* 2001; **154** : 221-236.

40. Bornman JF. Target sites of UV-B radiation in photosynthesis of higher plants. *J Photochem Photobiol B Biol* 1989; **4** : 145-158.

41. Cullen JJ, Neale PJ, Lesser MP. Biological weighting function for the inhibition of phytoplankton photosynthesis by ultraviolet radiation. *Science* 1992; **258** : 646-650.

42. Helbling EW, Villafañe VE, Ferrario M, Holm-Hansen O. Impact of natural ultraviolet radiation on rates of photosynthesis and on specific marine phytoplankton species. *Mar Ecol Prog Ser* 1992; **80** : 89-100.

43. Lesser MP. Oxidative stress in marine environments: biochemistry and physiological ecology. *Annu Rev Physiol* 2006; **68** : 253-278.

44. Villafañe VE, Marcoval MA, Helbling EW. Photosynthesis versus irradiance characteristics in phytoplankton assemblages off Patagonia (Argentina): temporal variability and solar UVR effects. *Mar Ecol Prog Ser* 2004; **284** : 23-34.

45. Arrigo KR. Impact of ozone depletion on phytoplankton growth in the Southern Ocean: large scale partial and temporal variability. *Mar Ecol Prog Ser* 1994; **114** : 1-12.

46. Neale PJ, Banaszak T, Jarriel CR. Ultraviolet sunscreens in *Gymnodinium sanguineum* (Dinophyceae): mycosporine-like amino acids protect against inhibition of photosynthesis. *J Phycol* 1998; **34** : 928-938.

47. Helbling EW, Gao K, Goncalves RJ, Wu H, Villafañe VE. Utilization of solar UV radiation by coastal phytoplankton assemblages off SE China when exposed to fast mixing. *Mar Ecol Prog Ser* 2003; **259** : 59-66.

48. Karentz D, Cleaver JE, Mitchell DL. Cell survival characteristics and molecular responses of Antarctic phytoplankton to ultraviolet-B radiation. *J Phycol* 1991; **27** : 326-341.

49. Karentz D, Cleaver JE, Mitchell DL. DNA damage in the Antarctic. *Nature* 1991; **350** : 28.

50. Tirlapur U, Scheuerlein R, Häder D-P. Motility and orientation of a dinoflagellate, *Gymnodinium*, impaired by solar and ultraviolet radiation. *FEMS Microbiol Ecol* 1993; **102** : 167-174.

51. Neale PJ, Davis RA, Cullen JJ. Interactive effects of ozone depletion and vertical mixing on photosynthesis of Antarctic phytoplankton. *Nature* 1998; **392** : 585-589.

52. Häder D-P. Ecological consequences of photomovement in microorganisms. *J Photochem Photobiol B Biol* 1988; **1** : 385-414.

53. Carreto JI, Lutz VA, De Marco SG, Carignan MO. Fluence and wavelength dependence of mycosporine-like amino acid synthesis in the dinoflagellate *Alexandrium excavatum*. In: Graneli E, Edler L, Sundström B, Anderson DM, editors. Toxic Marine Phytoplankton. New York: Elsevier, 1990. pp. 275-279.

54. Carreto JI, Carignan MO, Daleo G, De Marco SG. Occurrence of mycosporine-like amino acids in the red tide dinoflagellate *Alexandrium excavatum*: UV-protective compounds? *J Plankton Res* 1990; **12** : 909-921.

55. Dunlap WC, Rae GA, Helbling EW, Villafañe VE, Holm-Hansen O. UV-absorbing compounds in natural assemblages of Antarctic phytoplankton. *Antarct J U S* 1995; **30** : 323-326.

56. Helbling EW, Chalker BE, Dunlap WC, Holm-Hansen O, Villafañe VE. Photoacclimation of Antarctic diatoms to solar ultraviolet radiation. *J Exp Mar Biol Ecol* 1996; **204**: 85-101.

57. Vernet M, Whitehead K. Release of ultraviolet-absorbing compounds by the red-tide dinoflagellate *Lingulodinium polyedra*. *Mar Biol* 1996; **127** : 35-44.

58. Xiong F, Komenda J, Kopecky J, Nedbal L. Strategies of ultraviolet-B protection in microscopic algae. *Physiol Plant* 1997; **100** : 378-388.

59. Klisch M, Sinha RP, Richter PR, Häder D.P. Mycosporine-like amino acids (MAAs) protect against UV-B-induced damage in *Gyrodinium dorsum* Kofoid. *J Plant Physiol* 2001; **158** : 1449-1454.

60. Xiong F, Kopecky J, Nedbal L. The occurrence of UVB absorbing mycosporine-like amino acids in freshwater and terrestrial microalgae. *Aq Bot* 1999; **63** : 37-49.

61. Vernet M, Neori A, Haxo FT. Spectral properties and photosynthetic action in red-tide populations of

Prorocentrum micans and *Gonyaulax polyedra*. *Mar Biol* 1989; **103** : 365-371.

62. Llewellyn CA, Mantoura RFC. A UV absorbing compound in HPLC pigment chromatograms obtained from Icelandic Basin phytoplankton. *Mar Ecol Prog Ser* 1997; **158** : 283-287.

63. Dunlap WC, Shick JM. Ultraviolet radiation-absorbing mycosporine-like amino acids in coral reef organisms: a biochemical and environmental perspective. *J Phycol* 1998; **34** . 418-430.

64. Garcia-Pichel F. The absorption of ultraviolet radiation by microalgae: simple optics and photobiological implications. *Sci Mar* 1996; **60** : 73-79.

65. Carreto JI, De Marco SG, Lutz VA. UV-absorbing pigments in the dinoflagellates *Alexandrium excavatum* and *Prorocentrum micans*. Effects of light intensity. In: Okaichi T, Anderson DM, Nemoto T, editors. Red Tides, Biology, Environmental Science and Toxicology. New York: Elsevier, 1989. pp. 333-336.

66. Marchant HJ, Davidson AT, Kelly GJ UV-B protecting compounds in the marine alga *Phaeocystis pouchetti* from Antarctica. *Mar Biol* 1991; **109** : 391-395.

67. Villafañe VE, Helbling EW, Holm-Hansen O, Chalker BE. Acclimatization of Antarctic natural phytoplankton assemblages when exposed to solar ultraviolet radiation. *J Plankton Res* 1995; **17** : 2295-2306.

68. Riegger L, Robinson D. Photoinduction of UV-absorbing compounds in Antarctic diatoms and *Phaeocystis antarctica*. *Mar Ecol Prog Ser* 1997; **160** : 13-25.

69. Klisch M, Häder D-P Mycosporine-like amino acids in the marine dinoflagellate *Gyrodinium dorsum*: induction by ultraviolet irradiation. *J Photochem Photobiol B: Biol* 2000; **55** : 178-182.

70. Klisch M, Häder D.-P. Wavelength dependence of mycosporine-like amino acid synthesis in *Gyrodinium dorsum*. *J Photochem Photobiol B· Biol* 2002; **66** : 60-66.

71. Sinha RP, Klisch M, Gröniger A, Häder D-P. Ultraviolet-absorbing/screening substances in cyanobacteria, phytoplankton and macroalgae. *J Photochem Photobiol B Biol* 1998; **47** : 83-94.

72. Lüning K. Meeresbotanik: Verbreitung, Ökophysiologie und Nutzung der marinen Makroalgen. Stuttgart: Thieme Verlag. 1985.

73. Hanelt D. Photoinhibition of photosynthesis in marine macroalgae. *Sci Mar* 1996; **60** : 243-248.

74. Franklin LA, Forster RM. The changing irradiance environment: consequences for marine macrophyte physiology, productivity and ecology. *Eur J Phycol* 1997; **32**: 207-232.

75. Bischof K, Hanelt D, Wiencke C. UV-radiation can affect depth zonation of Antarctic macroalgae. *Mar Biol* 1998; **131** : 597-605.

76. Pakker H, Breeman AM. Effects of ultraviolet B radiation on macroalgae: DNA damage and repair. *Phycologia* 1997; **36** : p. 82.

77. Aguilera J, Jiménez C, Figueroa FL, Lebert M, Häder DP. Effect of ultraviolet radiation on thallus absorption and photosynthetic pigments in the red alga *Porphyra umbilicalis*. *J Photochem Photobiol B· Biol* 1999; **48** : 75-82.

78. Häder D-P, Lebert M, Sinha RP, Barbieri ES, Helbling EW. Role of protective and repair mechanisms in the inhibition of photosynthesis in marine macroalgae. *Photochem Photobiol Sci* 2002; **1** : 809-814.

79. Hanelt D, Huppertz K, Nultsch W. Daily course of photosynthesis and photoinhibition in marine macroalgae investigated in the laboratory and field. *Mar Ecol Prog Ser* 1993; **97** : 31-37.

80. Pérez-Rodríguez E, Gómez I, Karsten U, Figueroa FL. Effects of UV radiation on photosynthesis and excretion of UV-absorbing compounds of *Dasycladus vermicularis* (Dasycladales, Chlorophyta) from southern Spain. *Phycologia* 1998; **37** : 379-387.

81. Gröniger A, Hallier C, Häder D-P. Influence of UV radiation and visible light on *Porphyra umbilicalis*: photoinhibition and MAA concentration. *J Appl Phycol* 1999; **11** : 437-445.

82. Häder D-P, Herrmann H, Santas R. Effects of solar radiation and solar radiation deprived of UV-B and total UV on photosynthetic oxygen production and pulse amplitude modulated fluorescence in the brown alga, *Padina pavonica*. *FEMS Microbiol Ecol* 1996; **19** : 53-61.

83. Hanelt D, Wiencke C, Karsten U, Nultsch W. Photoinhibition and recovery after high light stress in different developmental and life-history stages of *Laminaria saccharina* (Phaeophyta). *J Phycol* 1997; **33** : 387-395.

84. Herrmann H, Häder D-P, Köfferlein M, Seidlitz HK, Ghetti F. Effects of UV radiation on photosynthesis of phytoplankton exposed to solar simulator light. *J. Photochem Photobiol B: Biol* 1996; **34** : 21-28.

85. Talarico L. Phycobiliproteins and phycobilisomes in red algae: adaptive responses to light. In: Figueroa FL, Jiménez C, Pérez-Lloréns JL, editors. Underwater Light and Algal Photobiology. *Sci Mar* 1996; **60** (Supp. 1), pp. 205-222.

86. Sinha RP, Barbieri ES, Lebert M, Helbling EW, Häder D-P. Effects of solar radiation on phycobiliproteins of marine red algae. *Trends Photochem Photobiol* 2003; **10** : 149-157.

87. Algarra P, Niell P. Short-term pigment response of *Corallina elongata* Ellis *et* Solander to light intensity. *Aquat Bot* 1990; **36** : 127-138.

88. Hanelt D, Jaramillo JM, Nultsch W, Senger S, Westermeier R. Photoinhibition as a regulative mechanism of photosynthesis in marine algae of Antarctica. *Serie Cient Inst Antarct* 1994; **44** : 67-77.

89. Gomez I, Thomas DN, Wiencke C. Longitudinal profiles of growth, photosynthesis and light independent carbon fixation in the Antarctic brown alga *Ascoseira mirabilis*. *Bot Mar* 1995, **38** : 157-164.

90. Niyogi KK. Safety valves for photosynthesis. *Curr Opin Plant Biol* 2000; **3** : 455-460.

91. Karsten U, Sawall T, Wiencke C. A survey of the distribution of UV-absorbing substances in tropical macroalgae. *Phycol Res* 1998; **46** : 271-279.

92. Tsujino I, Saito T. Studies in the compounds specific for each group of marine algae. I. Presence of characteristic ultraviolet absorbing material in Rhodophyceae. *Bull Fac Fish, Hokkaido Univ* 1961; **12** : 49-58.

93. Karsten U, Sawall T, Hanelt D, Bischof K, Figueroa FL, Flores-Moya A, Wiencke C. An inventory of UV-absorbing mycosporine-like amino acids in macroalgae from polar to warm-temperate regions. *Bot Mar* 1998; **41** : 443-453.

94 Karentz D, McEuen FS, Land MC, Dunlap WC. Survey of mycosporine-like amino acid compounds in Antarctic marine organism. potential protection from ultraviolet exposure. *Mar Biol* 1991; **108** : 157-166.

95. Häder D-P, Figueroa FL. Photoecophysiology of marine macroalgae. *Photochem Photobiol* 1997; **66** . 1-14

96. Maegawa M, Kunieda M, Kida W. Difference of the amount of UV absorbing substance between shallow and deep-water red algae. *Jpn J Phycol* 1993; **41** : 351-354.

97. Helbling EW, Barbieri ES, Sinha RP, Villafañe VE, Häder D-P. Dynamics of potentially protecting compounds in Rhodophyta species from Patagonia (Argentina) exposed to solar radiation. *J Photochem Photobiol B: Biol* 2004; **75** : 63-71.

98. Sinha RP, Klisch M, Gröniger A, Häder D-P. Mycosporine-like amino acids in the marine red alga *Gracilaria cornea*-effects of UV and heat. *Env Exp Bot* 2000; **43** : 33-43.

99. Gröniger A, Häder D-P. Induction of the synthesis of an UV-absorbing substance in the green alga *Prasiola stipitata*. *J Photochem Photobiol B: Biol* 2002; **66** : 54-59.

100. Franklin LA, Kräbs G, Kuhlenkamp R. Blue light and UV-A radiation control the synthesis of mycosporine-like amino acids in *Chondrus crispus* (Florideophyceae). *J Phycol* 2001; **37** : 257-270.

Proc. Nat. Acad. Sci. India, Sect. B, Vol. 78, Spl. Issue, 2008

Physico-chemical and biological characterization of the large Oxbow Surhatal Wetland

B.D. TRIPATHI*, ALKA R. UPADHAYAY and VINITA PATHAK

Centre for Environmental Science and Technology, Banaras Hindu University

**Coordinator Centre for Environmental Science and Technology, Banaras Hindu University-221005.*

**e-mail bdt_cest@rediffmail.com*

Abstract

Present research work deals with the examination of physico-chemical and biological properties of the water of the 'Surha Tal'. It is an Ox-bow kind of lake which occupies an area of 34.32 sq. km. It is evident from the physical and chemical analysis that the values of dissolved solids (10.9±7 mg/l), total suspended solids 48.7±2.5 mg/l, dissolved Oxygen (10.9±0.7 mg/l), biological oxygen demand (4.8±0.2 mg/l) were more than the normal standard. The pH of water was observed as partly acidic and mostly alkaline. Out of the different nutrients, nitrogen (45.5±0.2 mg/l) and Phosphorus (1.2±0.002 mg/l) were more than the required amount. The productivity of phytoplankton was maximum in March (2.83 g/carbon/m^2/day) and minimum (0.32 g/cargon/m^2/day) during August.

Aquatic plants were represented by a total of 35 species, whose number was maximum during rains, fewer during winters and minimum during summers.

Key words: Surhatal, dissolved solids, total suspended solids, dissolved oxygen, biological oxygen demand, pH, Nitrogen, Phosphorus, Productivity, Phytoplankton.

सारांश

प्रस्तुत शोध में सुरहा ताल के जल के भौतिक–रासायनिक एवं जैविक गुणो का परीक्षण किया गया है। यह एक "आक्सी बो" प्रकार की झील है जो 34.32 वर्ग किमी क्षेत्र मे फैली हुई है। जल के भौतिक एव रासायनिक गुणो के परीक्षणो से यह स्पष्ट है कि जल में घुलित ठोस पदार्थ (10.9±.07 मि ग्रा /ली) कुल विलयी ठोस 48.7±2 5 मि.ग्रा /ली. घुलित आक्सीजन 10.9±.07 मि.ग्रा./ली) जैविक आक्सीजन मॉग (4 8±0.2 मि.ग्रा /ली) की मात्रा मानको से अधिक थी। जल का पी.एच. आशिक अम्लीय और अधिकाशतः क्षारीय पाया गया। विभिन्न पोषक तत्वो में नाइट्रोजन (45.4±0 2 मि.ग्रा./ली) और फास्फोरस (1.2±0 002 मि ग्रा./ली) अधिक मात्रा मे उपस्थित पाये गये। पादप–उत्प्लावक की उत्पादकता मार्च मे सर्वाधिक (2.83 ग्राम कार्बन/मी^{2}/दिन) तथा अगस्त मे न्यूनतम (0.32 ग्राम कार्बन/मी^{2}/दिन) पायी गयी।

जलीय पौधो की कुल 35 प्रजातिया पायी गई, जिनकी सर्वाधिक सख्या बरसात में, उसके पश्चात जाडे मे तथा सबसे कम गर्मी के मौसम मे पायी गयी।

सांकेतिक शब्द : सुरहा ताल, विलयी ठोस, कुल निलंबित ठोस, घुलित आक्सीज़न, जैविक आक्सीजन माग, पी एच , नाइट्रोजन, फास्फोरस, उत्पादकता, पादप उत्प्लावक

Introduction

Wetlands are areas where water covers the soil, or is present either at or near the surface of the soil all year or for varying periods of time during the year, mainly during the growing season. Water saturation (hydrology) largely determines how the soil develops and the types of plant and animal communities living in and on the soil. Wetlands are valuable resources for various reasons. They contribute to the self-purification capacity of river systems and provide storage for excess river water, reducing the risks of flooding in inhabited areas. Additionally, they sustain specific habitats for valuable ecosystems. Wetlands are a target of contamination, yet they can be deliberately employed to treat contaminated water.[1] Wetlands may support both aquatic and terrestrial species. They are designed to take advantage of many of the processes that occur in natural wetlands, but do so within a more controlled environment.[2] In dry environments lack of water may limit the hydrological requirements of biogeochemical processes removing nutrients in wetlands[3,4,5]. The prolonged presence of water creates conditions that favour the growth of specially adapted plants (hydrophytes) and promote the development of characteristic wetland (hydric) soils[6]. Wetlands play a key regulatory role in discharge and recharge of water and nutrients and act as sink for waters. They provide an excellent habitat for a rich biodiversity.

Various aquatic macrophytes have been tested as biofilters to purify water by removing nitrogen and phosphorus, elements that cause eutrophication Wetlands are also among the most efficient productive ecosystem as they combine the best of terrestrial and aquatic environments. They are richest sites of biodiversity.

The flood shows a pronounced effect on the growth of submerged macrophytes and their distribution.

Surhatal lake was subjected as sanctuary in the year 1991 for the conservation, protection and management of habitat. Thus it has become a conservation site as destruction or damage, exploitation, hunting and grazing, are all prohibited except by or under the direction and control of the authorities. Sanctuary status restricts and prohibits human settlement and other human activities. No alteration of the boundaries of a sanctuary can be made except on a resolution passed by the Legislature of the State

Material and Methods

Study site

Surhatal lake lies in the Ballia district of Uttar Pradesh. Ballia is the easternmost part of the Uttar Pradesh state bordering Bihar State. It comprises an irregularly shaped tract extending westward from the confluence of the Ganga and the Ghaghra, the former separating it from Bihar in the south and the latter from Deoria and Bihar in the north and east respectively. The boundary between Ballia and Bihar is determined by the deep streams of these two rivers. It is bounded on the west by Azamgarh, on the north by Deoria district on the north-east and south-east by state of Bihar and on the south-west by Ghazipur district. The district lies between the parallels of 25°33' and 26°11' North latitudes and 83°38' and 84°39' East longitudes (Map - 1). Surhatal is an Ox-bow type of lake with a rather shallow basin. The lake is not having definite banks and the watery area pass imperceptibly into higher and drier grounds which themselves are liable to flooding.

The lake shows following morphometric data

Bed level	53.985 m (above mean sea level)
Low flood level	54.90m (above mean sea level)
High flood level	58.95 m (above mean sea level)
Catchments area	230.0 sq km
Maximum depth	4.82 m (above mean sea level)
Area submerged	
Maximum	5180.16 ha.
Minimum	277.0 ha.
Capacity	
Maximum	367 Mc ft.
Minimum	15 Mc ft.
Length	6.3 km
Width	5.0 km

Climate

The climate of the district is moist and moderate except in the warm summer and cold winter seasons. The year may be divided into four seasons: the winter, which lasts from about the latter half of November to February: the summer, from March to about the middle of June; the south-west monsoon season, which constitutes the period from about the middle of June to the end of September: and the post-monsoon or transitional season which covers October to the first half of November.

Rainfall

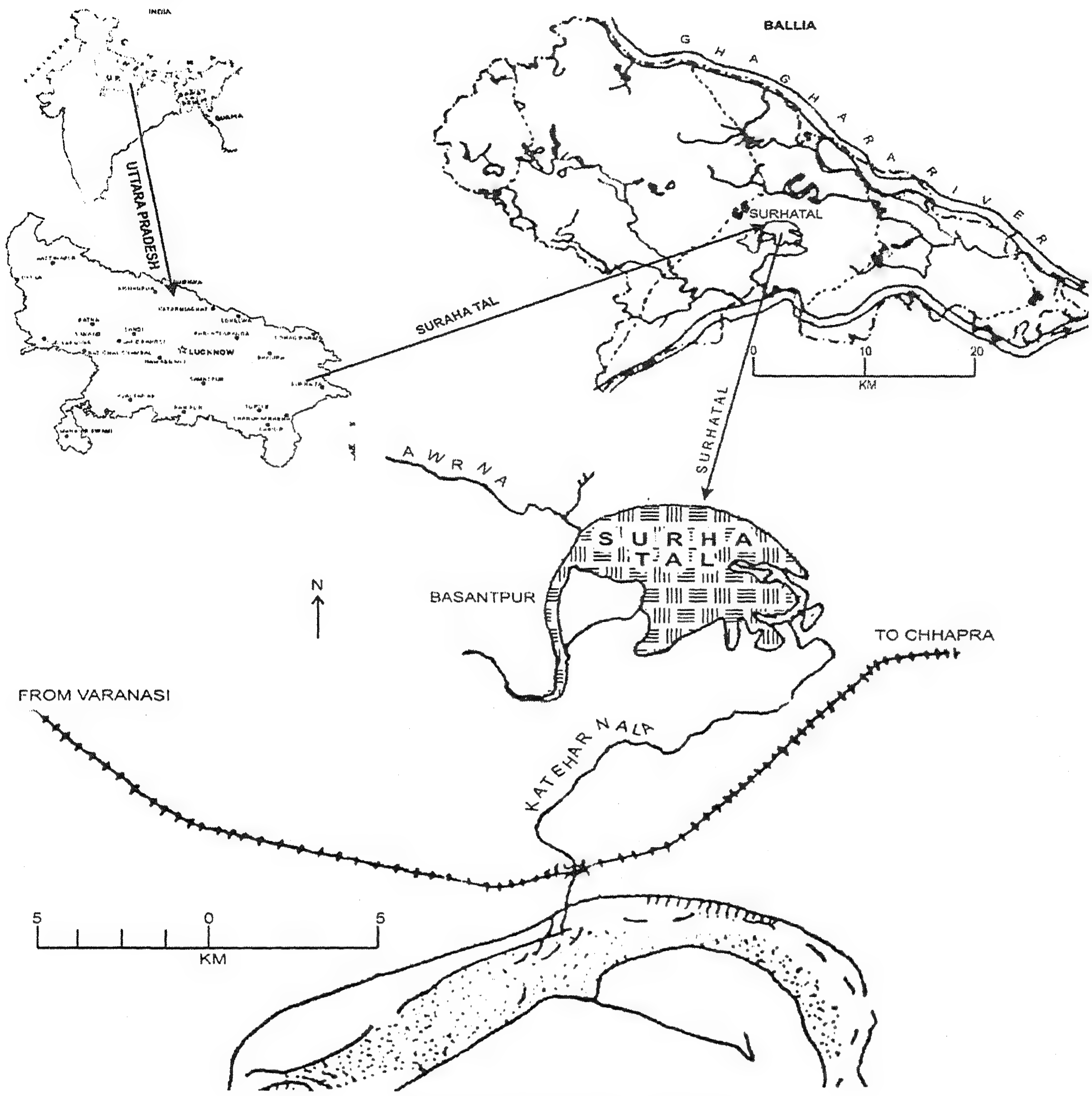
The average annual rainfall in the district is 1,013.1 mm. (39.89"). About 88 per cent of the annual rainfall is received during the south-west monsoon months (June to September), August being the rainiest month.

Temperature and humidity

May is generally the hottest month with the mean daily maximum temperature at 41.8°C. and the mean

Table 1 - Thermal stratification data for April 2006 in Surhatal Lake

Depth of Water (c.m.)	Temperature oC	
	8:00 - 9:00 a.m.	1:00 - 2:00 p.m.
10	26.4	31.0
50	26.3	30.4
100	26.2	29.0
150	26.2	28.7
200	26.2	28.0
250	26.2	27.8



Map depicting location of *Surhatal*

daily minimum at 25.4° C. January is usually the coldest month with the mean daily maximum, temperature dropping to 23.9° C and the mean daily minimum to about 9.9° C. The relative humidity is generally high during the south-west monsoon season, being 70%.

Physicochemical characteristics of Suhartal water

Physicochemical characteristics of water such as temperature, transparency, pH, total dissolved solids, total suspended solids, total alkalinity, dissolved oxygen, biochemical oxygen demand, nitrate, phosphate and calcium was done. Mud was analyzed for total nitrogen and phosphorus. Samples were collected at fortnightly intervals. Three replicates of each sample (water and mud) were used. Twelve sampling stations were identified representing approximately the entire area of the lake. Standard methods[7] were used for the sampling and analysis. Sampling was also done for identification of aquatic macrophytes.

Biological characteristics of Suhartal water

Phytoplankton productivity was measured using Garder and Gran's Light and Dark bottole technique.[8] All macrophyte present in Surhatal wetland growing in different months were collected and identified.

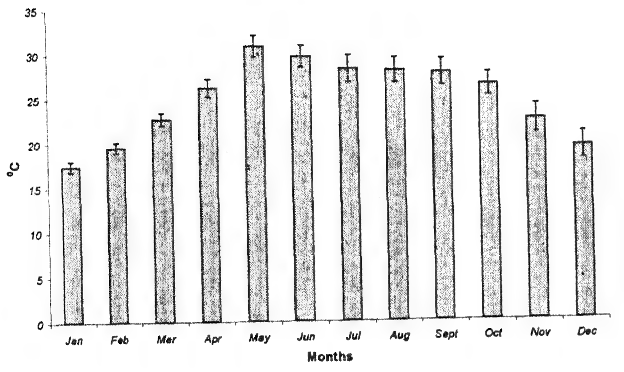


Fig. 1 - Monthly variation in temperature in Surhatal lake.

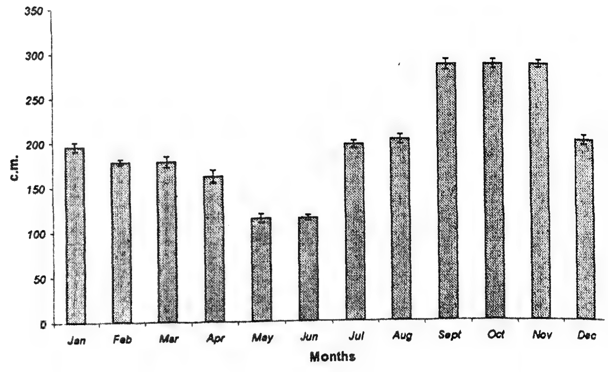


Fig. 2 - Monthly variation in depth in littoral zone.

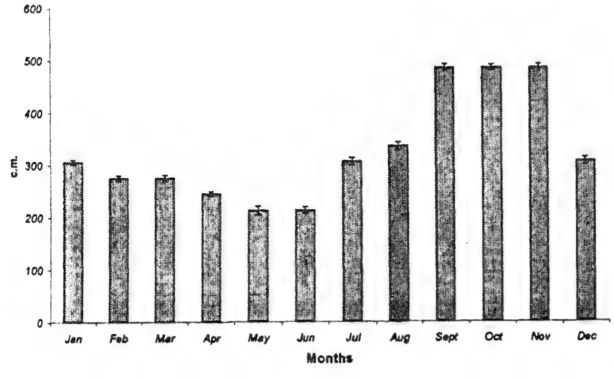


Fig. 3 - Monthly variation in depth in pelagic zone.

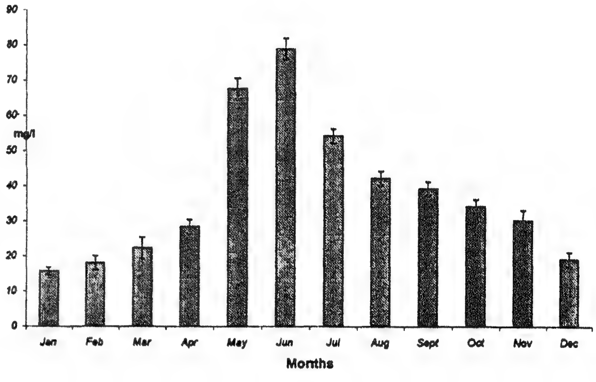


Fig. 4 - Monthly variation in total dissolved solids of Surhatal lake.

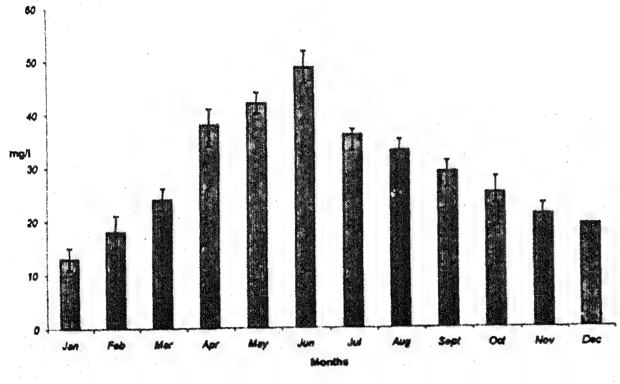


Fig. 5 - Monthly variation in total suspended soilds of Surhatal lake.

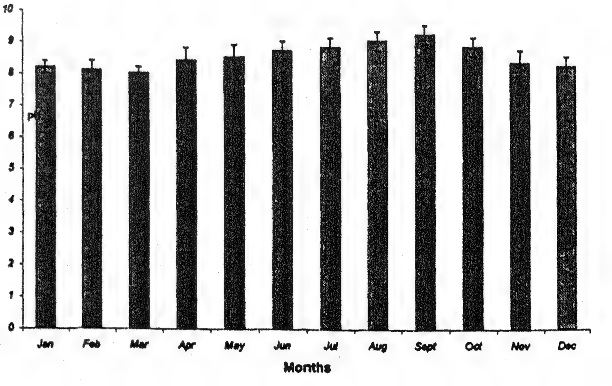


Fig. 6 - Monthly variation in pH of Surhatal lake.

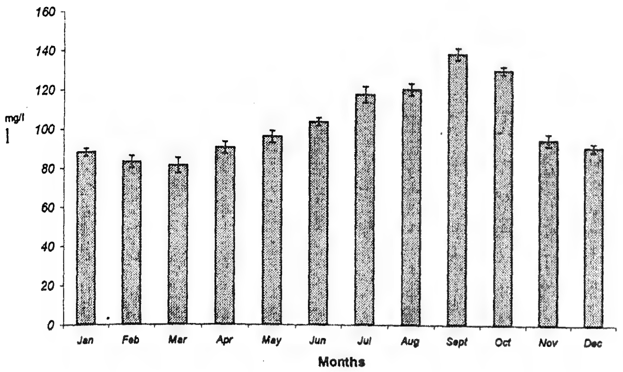


Fig. 7 - Monthly variation in total alkalinity Surhatal lake.

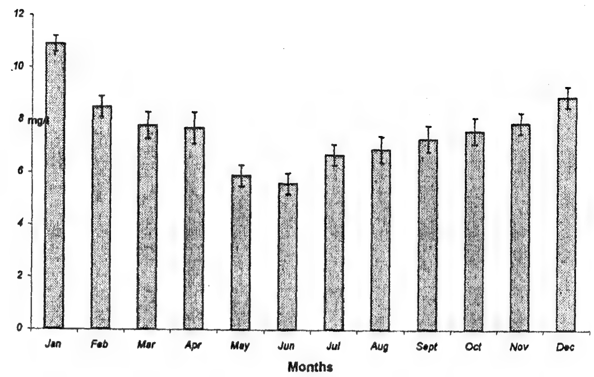


Fig. 8 - Monthly variation on dissolved oxygen of Surhatal lake.

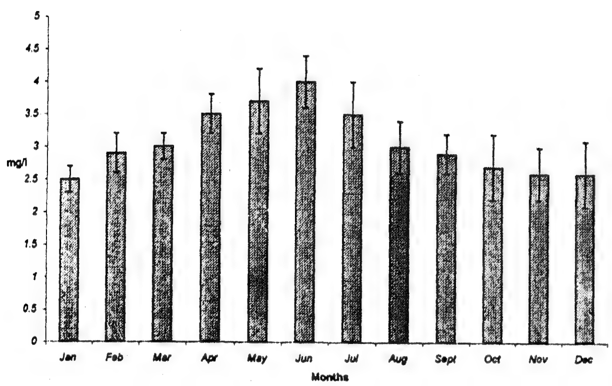


Fig. 9 - Monthly variation in biochemical oxygen demand of Surhatal lake.

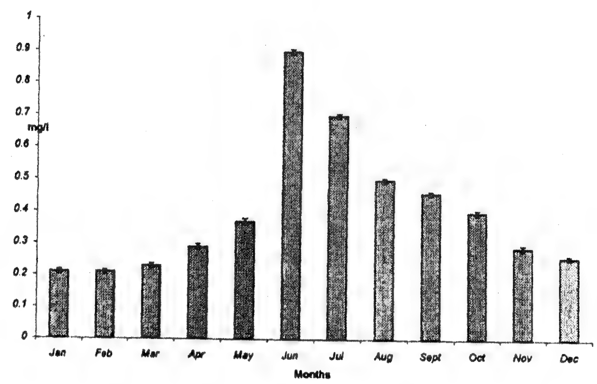


Fig. 10 - Monthly variation in nitrate of Surhatal lake.

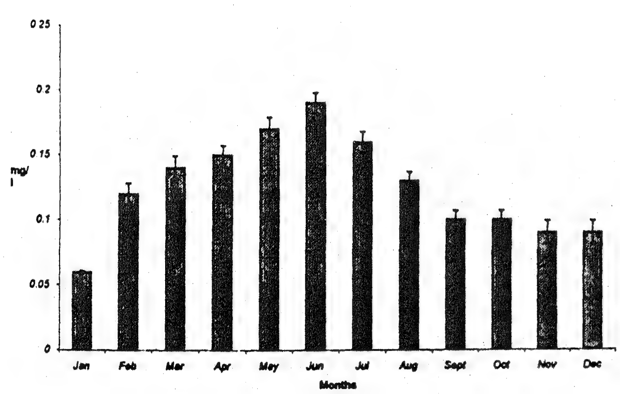


Fig. 11 - Monthly variation in Phosphate of Surhatal lake.

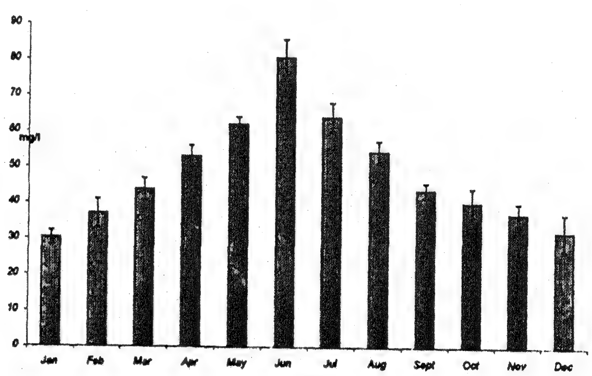


Fig. 12 - Monthly variation on calcium of Surhatal lake.

Results and Discussion

Temperatu 〉

Temperature is one of the most important factors of an aquatic ecosystem, which influences the chemical and biological activities. It also plays an important role in solubility of gases[9] and alters the saturation values of solids and gases in water, which may be due to variations in ambient air temperature during different months. Temperature was recorded lowest in January and highest in May as 17.4±1.2 and 30.8±1.3 oC respectively (Fig.1). Temperature showed little variation in the months. Temperature plays an important role in controlling the phytoplankton density and also affects the growth and distribution of macrophytes. Temperature changes at surface and underwater zones help in upturning of water. Analysis of variance was highly significant among months ($p<0.001$).

Depth

Depth was measured for littoral and pelagic zones. Littoral zone was observed highest as 283±6.8 c.m. in September, October and November months and lowest 114±4.3 cm. in May and June (Fig. 2). Pelagic zone was highest as 484±5.6 c.m. in September, October and November and lowest 212±3.9 c.m. in May and June (Fig. 3). Depth changes often reflect the nutrient concentration or dilution levels.

Total dissolved solids (TDS)

Total dissolved solids denote mainly the various kinds of minerals present in the water. Determination of dissolved and suspended matter is made with filtered and unfiltered portions of sample. In natural waters, the dissolved solids consist mainly of bicarbonates, carbonates, sulphates, chlorides, nitrates and possibly phosphates of calcium, magnesium, sodium and potassium with traces of iron, manganese and other substances. Total dissolved solids were recorded highest as 78.6±3.2 in June and lowest as 15.7±1.5 mg/l in January (Fig. 4). Analysis of variance revealed positive and significant among months ($p<0.001$).

Total suspended solids (TSS)

Total suspended solids denote suspended impurities present in the water. Suspended solids are very degrading in wetlands for many reasons. Suspended solids containing much organic matter may cause putrefaction and consequently the waste bodies may be devoid of dissolved oxygen. Mineral and organic suspended matter can lead to siltation. In most of the cases they are of organic nature and pose severe problems of water pollution. Total suspended solids were recorded highest as 48.7±2.5 in June and lowest as 13±1.5 mg/l in January (Fig. 5). Analysis of variance revealed positive and significant among months ($p<0.001$).

pH

pH of water body refers to its hydrogen ion activity. It serves as an index to denote the extent of pollution caused by acidic and alkaline wastes. The adverse effects of most of the acids appear below pH 5 and of alkalis above 9.5. In natural water pH usually ranges from 6.5 to 8.5. The pH was highest in September as 9.2±0.7 and lowest as 8.2±0.9 in March (Fig. 6). Usually the acidic waters are least buffered and less productive, because appreciable quantities of bicarbonates are not dissolved in such waters to give CO2 for efficient photosynthesis. Analysis of variance was positive and significant among months ($p<0.001$).

Total alkalinity

The alkalinity of water is its quantitative capacity to neutralize a strong acid to a designated pH. Alkalinity in surface water is induced due to the presence of carbonates, bicarbonates and hydroxyl ions as well as phosphates, silicates, borates or other bases[7,10]. Total alkalinity was recorded highest 138.2±5.2 in September and lowest 95.7±3.4 mg/l in March (Fig. 7). Analysis of variance was significant ($p<0.001$) between different months.

Dissolved oxygen (DO)

The presence of dissolved oxygen is essential to maintain a rich diversity and to keep proper balance of various populations thus making the water body healthy. The concentration of DO in natural and wastewater depends on the physical, chemical and biological activities. Main sources of DO in aquatic bodies are direct diffusion of O_2 from the atmosphere and that produced in photosynthetic activities. It is highly influenced by wind generating waves and the intensity and availability of light and the type and density of photosynthetic organisms. DO decreases with increase in temperatures being only 8.30 mgL^{-1} at 25 0C and zero at 100 0C. From the present observation

highest DO content (10.9±0.7 mgL^{-1}) is seen during the month of January and least (5.6±0.3 mgL^{-1}) during the month of June. (Fig. 8) Analysis of variance was significant ($p<0.001$) between different months.

Biochemical oxygen demand (BOD)

An estimate of oxygen consumed in the unit volume of water over a period of time is called biochemical oxygen demand. The concept is widely used to (i) determine the degree of pollution in water bodies at any time and their self purification capacity, (ii) the pollution load of wastewater, and (iii) efficiency of wastewater treatment plants. Higher BOD values indicate higher consumption of oxygen to degrade higher amounts of organic matter present in the water, indicating higher pollution load. Biochemical oxygen demand was recorded highest as 4.0±0.2 mgL^{-1} in June and lowest as 2.5±0.2 mgL^{-1} in January (Fig. 9). Analysis of variance was highly significant ($p<0.001$) among different months. BOD values ranging from 2.5 - 4.0 mgL^{-1} revealed the fact that the water of Surahatal wetland is under healthy state. This provides favourable condition for the rich flora in any lake.

Nitrate

Nitrate in natural waters depends upon the rates of nitrification and denitrification as well as the rate at which, it is taken up, by the primary producers. Most surface waters are deficient in nitrate. The most important source of the nitrate is biological oxidation of organic nitrogenous substances. Runoff from agricultural fields also contains nitrate, which is the highest oxidized form of nitrogen. Atmospheric nitrogen fixed into nitrates by the nitrogen fixing organisms is also a significant contributor to nitrates in the water. Nitrate was highest as 0.9±0.05 in June and lowest as 0.21±0.001 mg/l in January (Fig. 10). Lower value of nitrate in winter months may be due to less activity of nitrifying bacteria, utilization by macrophytes and algal population. Similar results have also been reported by previous workers.[11,12]. Analysis of variance was highly significant ($p<0.001$) among different months. The Nitrate concentration is reflective of a healthy and productive state of the Surahatal wetland.

Phosphate

Phosphorus occurs in natural water and in wastewater as phosphates. Phosphate is an essential plant nutrient, which is generally recognized as the chief limiting factor for the growth of producers in natural waters[13] and therefore, its determination in natural waters may be helpful in deriving significant conclusions regarding water quality. Phosphates also occur in the bottom sediments and in biological sludge both in inorganic and organic forms. Phosphate was

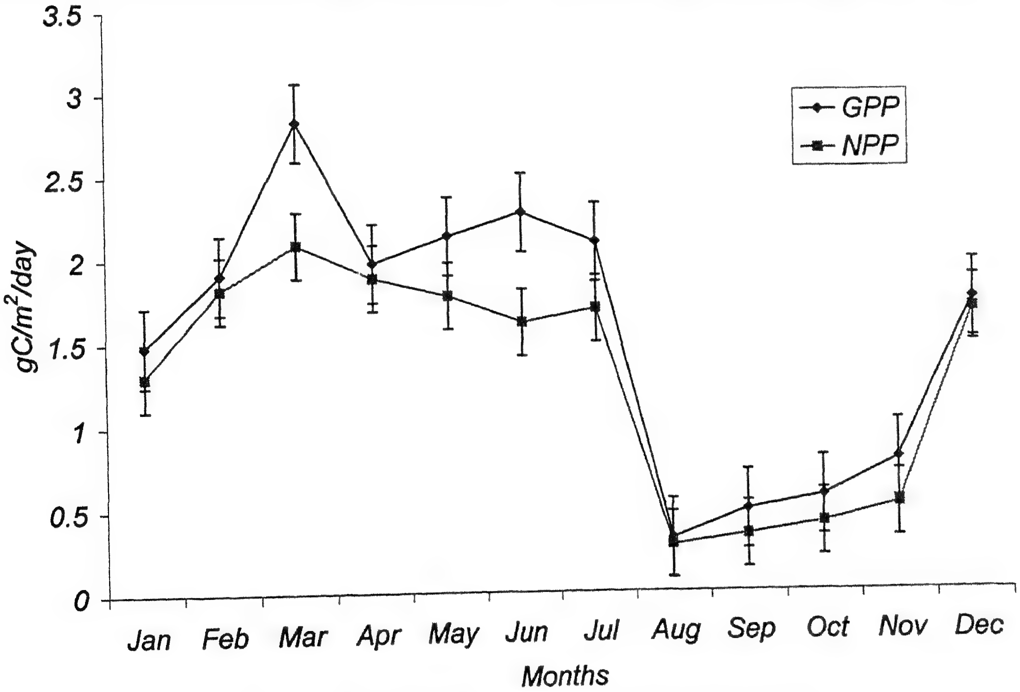


Fig. 13 - Phytoplankton productivity in Surhatal wetland

Table 2 - Composition of Macrophyte of Surhatal wetland.

	Plant Species	Life form
1.	*Aeschynomene aspera*	Marshy
2.	*Alternanthera sessilis*	Marshy
3.	*Aponogeton natans*	Floating leaved, Submerged
4.	*Azolla pinnata*	Free floating
5.	*Ceratophyllum demersum*	Submerged
6.	*Commelina benghalensis*	Marshy
7.	*Cyperus monocephalus*	Marshy
8.	*Cyperus platystylis*	Emergent
9.	*Eichhornia crassipes*	Free floating
10.	*Eleocharis plantaginea*	Emergent
11.	*Hydrilla verticellata*	Submerged
12.	*Hygroryzea arietata*	Floating leaved
13.	*Ipomea aquatica*	Floating leaved
14.	*Jussiaea repene*	Floating leaved
15.	*Limnophila heterophylla*	Floating leaved
16.	*Ludwigia paryiflora*	Emergent
17.	*Marsilea minuta*	Free floating
18.	*Najas graminea*	Submerged
19.	*Nelumbo nucifera*	Floating leaved, Emergent
20.	*Nymphaea nouchali*	Floating leaved
21.	*Nymphoides indicum*	Floating leaved
22.	*Oryza rufipogon*	Emergent
23.	*Oryza sativa*	Emergent
24.	*Ottelia alismoides*	Submerged
25.	*Paspalum acrobiculatum*	Marshy
26.	*Polygonum barbatum*	Marshy
27.	*Potamogeton crispus*	Submerged
28.	*Potamogeton pectinatus*	Submerged
29.	*Ranunculus sceleratus*	Marshy
30.	*Rotala rotundifolia*	Marshy
31.	*Sagittaria guayanensis*	Emergent, Marshy
32.	*Trapa natans*	Free floating
33.	*Utricularia flexucosa*	Free floating
34.	*Vallisnaria spiralis*	Submerged
35.	*Wolffia arrhiza*	Free floating

recorded highest as 0.19±0.002 in June and lowest as 0.06±0.001 mg/l in January (Fig. 11). Phosphate content of flowing water changes slightly from time to time, whereas, in stagnant water it remains more or less the same. However, in Suhartal very little variation in the months was recorded. Analysis of variance was highly significant ($p<0.001$) among different months. The Phosphate level reflects a good nutrient level but not too high to cause eutrophication.

Calcium

Calcium is one of the most abundant substances in natural water. It is present in high quantities in the rocks, from where it is leached to contaminate water. Concentration on Calcium is reduced at higher pH due to its precipitation as $CaCO_3$. It is one of the very important nutrients required by the organism. Calcium was highest as 80.7±3.4 in June and lowest as 30.2±2.1 mg/l in January (Fig. 12). Calcium precipitation could also be noticed on submerged leaves. Analysis of variance was highly significant ($p<0.001$) among different months.

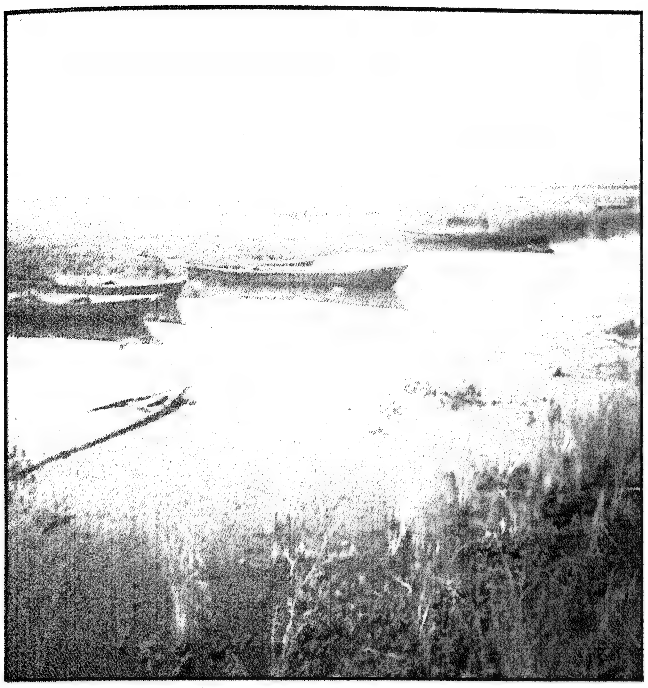
Nutrient status in mud of Surhatal lake

Total N

Total Kjeldal nitrogen is sum of ammonia nitrogen and organic nitrogen. A series of processes, including decomposition (of organic nitrogen), nitrification (of ammonia nitrite and nitrate), uptake of soluble forms by crops, soil absorption (of ammonium ion), denitrification (of nitrate to nitrogen gas), and volatilization (of ammonia gas), control the nitrogen budget of soil. Total N was recorded highest in June as 4.3±0.2 and lowest as 2.1±0.4 mg/l in January. Analysis of variance was highly significant ($p<0.001$) among different months. The total N in mud is several times more in mud than the NO_3 - N in water. As the nitrogen is used by submerged and floating plants, there is normally a release of additional nitrogen from the bottom mud. Therefore, a high nitrogen in mud is useful in the long run without causing eutrophication.

Available P

In natural waters, phosphorus occurs as orthophosphate and polyphosphate anions and in trace amounts, as organically bound phosphorus. Available P was highest in June as 1.2±0.002 and lowest as 0.18±0.01 mg/g in dry mud in January. Analysis of variance was highly significant ($p<0.001$) among



(a) Shallow water in Surhatal

(b) *Oryza sativa* growing in Surhatal

(c) Plants growing in thick organic matter

(d) Surhatal Vegetation

different months. A phosphorus rich mud is always good for a healthy and productive wetlands.

Phytoplankton Productivity

Primary productivity of an ecological system is defined as the rate at which radiant energy is stored by photosynthetic and chemosynthetic activities of producer organisms in the form organic substances which can be used as a food materials. The organic material synthesized by primary producer is utilized by the consumers inhabiting the system. All the material synthesized by the producer however, is not available to consumers. Carbon uptake as well as the production of oxygen, or the formation of organic compound or the gain of chemical energy of the system is reflected by the estimation of phytoplankton productivity.

In present study phytoplankton productivity was also measured. Gross and net productivities of phytoplankton are shown in Fig.-13. The lowest gross production of phytoplankton (0.32 $gC/m^2/day$) was observed during the month of August 2006, where as its highest value (2.83 $gC/m^2/day$) was recorded during the month of March 2006. Highest value of NPP (2.09 $gC/m^2/day$) was recorded during the month of March 06, where as least NPP (0.28 $gC/m^2/day$) was recorded during the months of August 06. Minimum values of GPP and NPP during the month of August indicate least productivity of the Surhatal wetland during mansoon season whereas highest values of the GPP and NPP during the month of March revealed highest productivity of the wetland during spring season. Similar observations have been made by Shukla *et al.*, 1989. From the above observations it is also revealed that Surhatal wetland has high phytoplankton productivity in comparison to other wetlands.

Floristic composition of Surhatal

Thirty five species of macrophytes were documented in the Surhatal during the study period January to December, 2006. Seasonal variation in the macrophytes was also recorded. Composition of aquatic macrophytes and their seasonal variations are shown in table-2 and 3 respectively.

Types of life forms of macrophytes

During present investigation following five types of life forms have been identified in the Surhatal lake.

Emergent

The rooted aquatic macrophytes with principal photosynthetic components emerging out of water[14]. They commonly occur on submerged soil where soil is covered up to 150 cm or more (in case or *Oryza sativa*) water level. The common species of the present group are *Cyperus platystylis, Eleocharis plantaginea, Ludwigia parviflora, Oryza rufipogon, Oryza sativa* and *Sagittaria guayanensi* (Table - 2).

Floating leaved

Macrophytes of this group occur on submerged soil in water depth of 30 cm to 350 cm. The habit is characterized by attached root system to substratum and leaves floating on water surface. Following species are recorded under this group: *Hygrorrhiza aristata, Ipomea aquatica, Jussiaea repens, Limnophylla heterophylla, Nelumbo nucifera, Nymphaea nouchali* and *Nymphoides indicum* (Table - 2).

Free floating

These plants are unattached to any substrate and float freely on water surface. However, in shallow water Eichhornia crassipes anchored to the soil with its well developed roots. Following species are recorded in this group: *Azolla pinnata, Eichhornia crassipes, Marsilia minuta, Trapa natans, Utricularia flexuosa* and *Wolffia arrhiza* (Table - 2).

Submerged

This life-form is characterized by the macrophytes growing under water in submerged state. This life form occurres usually in deep water in the pelagic region. The species recorded are : *Aponogeton natans, Ceratophyllum demersum, Chara braunii, Najas graminea, Ottelia alismoides, Potamogeton crispus, P. pectinatus, Vallisnaria spiralis* and *Hydrilla verticillata* (Table-2).

Marshy

These plants are differentiated from others as they occur on saturated soil on mud. Nine species are recorded on the drying margins of littoral zone as follows: *Aeschynomene aspera, Alternanthera sessilis, Commelina benghalensis, Cyperus monocephalus, Paspalum scrobiculatum, Polygonum barbatum, Ranunculus sceleratus* and *Sagittaria guayanensis*.

Table 3 - Seasonal changes in floristic composition of Surha Tal.

	Plant Species	Life form	Littoral			Pelagic		
			S	R	W	S	R	W
1.	*Aeschynomene aspera*	M	-	+	+	-	-	-
2.	*Alternanthera sessilis*	M	-	+	+	-	-	-
3.	*Aponogeton natans*	Fl, S	-	+	+	-	+	+
4.	*Azolla pinnata*	Ff	-	+	-	-	-	-
5.	*Ceratophyllum demersum*	S	-	-	+	+	+	+
6.	*Commelina benghalensis*	M	-	+	+	-	-	-
7.	*Cyperus monocephalus*	M	-	+	+	-	-	-
8.	*Cyperus platystylis*	E	+	+	+	-	-	-
9.	*Eichhornia crassipes*	Ff	+	+	+	+	-	-
10.	*Eleocharis plantaginea*	E	+	+	+	-	-	-
11.	*Hydrilla verticellata*	S	-	+	+	+	+	+
12.	*Hygroryzea arietata*	Fl	-	-	+	-	-	-
13.	*Ipomea aquatica*	Fl	-	+	+	-	-	-
14.	*Jussiaea repene*	Fl	+	+	-	-	-	-
15.	*Limnophila heterophylla*	Fl	-	+	+	+	-	-
16.	*Ludwigia paryiflora*	E	-	+	+	-	-	-
17.	*Marsilea minuta*	Ff	+	+	+	-	-	-
18.	*Najas graminea*	S	-	+	-	+	+	-
19.	*Nelumbo nucifera*	Fl,E	+	+	-	+	-	-
20.	*Nymphaea nouchali*	Fl	-	+	-	+	-	-
21.	*Nymphoides indicum*	Fl	+	+	+	+	-	+
22.	*Oryza rufipogon*	E	+	+	+	-	-	-
23.	*Oryza sativa*	E	-	+	+	-	-	-
24.	*Ottelia alismoides*	S	-	+	+	+	+	+
25.	*Paspalum acrobiculatum*	M	-	+	-	-	-	-
26.	*Polygonum barbatum*	M	-	+	+	-	-	-
27.	*Potamogeton crispus*	S	-	+	+	+	+	+
28.	*Potamogeton pectinatus*	S	-	+	+	+	+	+
29.	*Ranunculus sceleratus*	M	-	+	+	-	-	-
30.	*Rotala rotundifolia*	M	-	+	+	-	-	-
31.	*Sagittaria guayanensis*	E,M	-	+	+	-	-	-
32.	*Trapa natans*	Ff	+	+	+	-	-	-
33.	*Utricularia flexuosa*	Ff	-	+	+	+	+	+
34.	*Vallisnaria spiralis*	S	-	-	+	+	+	+
35.	*Wolffia arrhiza*	Ff	-	+	-	-	-	-

+ -> present; -> absent

S -> Summer; R -> Rainy; W -> Winter; E -> Emergent; Fl -> Floating leaved;

Ff -> Free floating; S -> Submerged; M -> Marshy ;

Seasonal changes in floristic composition

The number of species occurring in littoral zone were always higher than that of pelagic zone except for the summer season when most part of the littoral zone dries up and land plants colonize the area. However, no record for these terrestrial communities have been made.

The maximum number of 31 species have been recorded in the rainy season in littoral zone which corresponds to only nine in the pelagic zone for same season. In winter season 27 and 9 species have been recorded in littoral and pelagic zones, respectively. However, in summer months only 10 species have been recorded against a number of 14 species in the pelagic zone.

The species recorded in littoral zone are *Cyperus platystylis, Eichhornia crassipes, Eleocharis plantaginea, Jussiaea repene, Marsilea minuta, Nelumbo nucifera, Nymphoides indicum, Oryza rufipogon* and *Trapa natans* in summer season. In addition to above species *Aeschynomene aspera, Alternanthera sessilis, Aponogeton natans, Azolla pinnata, Commelina benghalen, Cyperus monocephalus, Hydrilla verticellata Hygroryzea arietata, Ipomea aquatica, Limnophila heterophylla, Ludwigia paryiflora, Najas graminea, Nymphaea nouchali, Oryza sativa, Ottelia alismoides, Paspalum acrobiculatum, Polygonum barbatum, Potamogeton crispus, Potamogeton pectinatus, Ranunculus sceleratus, Rotala rotundifolia, Utricularia flexucosa, Wolffia arrhiza* and *Sagittaria guayanensis* were also present in the rainy season. In winter season, the littoral zone shows the following species :

Aeschynomene aspera, Alternanthera sessilis, Aponogeton natans, Ceratophyllum demersum, Commelina benghalensis, Cyperus monocephalus, Cyperus platystylis, Eichhornia crassipes, Eleocharis plantaginea, Hygroryzea arietata, Ipomea aquatica, Limnophila heterophylla, Ludwigia paryiflora, Marsilea minuta, Nymphoides indicum, Oryza rufipogon, Oryza sativa, Ottelia alismoides, Polygonum barbatum, Potamogeton crispus, Potamogeton pectinatus, Ranunculus sceleratus, Rotala rotundifolia, Trapa natans, Utricularia flexucosa, Vallisnaria spiralis, Sagittaria guayanensis and *Hydrilla verticellata.*

In pelagic zone the maximum number of species was recorded in summer season. They are *Ceratophyllum demersum, Eichhornia crassipes, Limnophila heterophylla, Najas graminea, Nelumbo nucifera, Nymphaea nouchali, Nymphoides indicum, Ottelia alismoides, Potamogeton crispus, Potamogeton pectinatus, Utricularia flexucosa, Vallisnaria spiralis,* and *Hydrilla verticillata.* In rainy and winter season *Aponogeton natans, Ceratophyllum demersum, Ottelia alismoides, Potamogeton cirspus, P. Pectinatus, Hydrilla verticillata, Utricularia flexusa* and *Vallisneria spiralia* were the main constituent of pelagic vegetation. However, in addition to above *Najas graminea* and *Nymphoides indicum* occurred in rainy and winter seasons, respectively, in the pelagic region of the lake.

Conclusion

Present study revealed seasonal variations in water temperature of Surhatal wetland. Higher temperature during summer months and lower during winter may be associated with the ambient temperature. Highest concentration of dissolved oxygen during winter and lowest during summer indicate inverse relationship between DO and temperature. Inverse relationship between BOD and DO values also indicate that during summer months due to high BOD, population of microbes might have been increased and DO is utilized for biological oxidation of organic matter. Higher nitrogen content during summer may be associated with the release of nitrogen from the decomposition of organic matter.

Lower content of available phosphorus acts as a limiting factor which prevents the Surhatal wetland from eutrophication. Presence of 35 aquatic vascular plants and very high phytoplankton productivity is an indicator of highly productive wetland. (Plate 1) Thus this large Ox-bow wetland with rich flora and high primary productivity should be prevented from degradational forces.

Acknowledgement

Authors are thankful to the Ministry of Environment and Forest, Government of India for financial support.

References

1. Filip MG, Tack, Niels De Pauw, Gijs Du Laingand Diederik Rousseau. *Science of The Total Environment* 2007; 380 (3) : 1-2.

2. Hammer DA, Bastian RK. Wetlands ecosystems: natural water purifiers?. In: Hammer DA, editor. Constructed wetlands for wastewater treatment, Chelsea, Michigan: Lewis Publishers, 1989. 5-19.

3. Mandi L, Bouhoum K, Ouazzani N. Application of constructed wetlands for domestic wastewater treatment in an arid climate, *Water Sci Technol* 1998; **38 (1)** : 379-387.

4. Lissner J, Schierup HH, Comin FA, Astorga V. Effect of climate on the salt tolerance of two *Phragmites australis* populations. II. Diurnal CO_2 exchange and transpiration. *Aquat Bot* 1998; **64** : 330-335.

5. Comín FA, Menendez M, Pedrocchi C, Moreno S, Sorando R, Cabezas A, García M, Rosas V, Moreno D, González E, Gallardo B, Herrea JA, Ciancarelli C. Wetland restoration: Integrating. 2005.

6 Odum EP. Fundamentals of Ecology. Philadelphia: W.B. Saunders Company. 1971.

7. APHA, Standard Methods for the Examination of Water and Wastewaters. Washington DC: American Public Health Association, 1998.

8. Gaarder T, Gran HH. Investigation of the production of plankton in the Oslo Fjord. *Rapp et Proc Verb Cons Int Explor Mer* 1927; **42** : 1-48.

9. Reid GK. Ecology of Inland waters and Estuaries. New York : 1961.

10. Singh SP. Physico-chemical characteristics and macrophytes of Naukuchiya Tal, A mid attitude lake of Kumaun Himalaya (India). *Tropical Ecology* 1981; **22(1)** : 40-53.

11. Sculthorpe CD. The Biology of Aquatic Vascular Plants. New York: St. Martins Press, 610. 1967.

12. Tripath BD. Nitrogen and Phosphorus Removal-capacity of four Chosen Aquatic Macrophytes in Tropical Fresh-water Ponds. *Envr Cons* 1991; **18** : 143-147.

13. Tripathi BD, Mishra BP. Distribution of macrophytes and physiology of *Hydrilla verticillata* Casp. and *Lemna minor* Linn. in lotic and lentic aquatic ecosystems. *Ecol Env and Cons* 2004; **10 (1)** : 37-41.

14. Ambasht RS. Ecosystem study of a tropical pond in relation to primary production of different vegetation zones. *Hydrobiologia* 1971; **12** : 57-61.

Proc. Nat. Acad. Sci. India, Sect. B, Vol. 78, Spl. Issue, 2008

Use of geospatial technology for studies of catchment area of Loktak lake.

RAJKUMARI SUNITA DEVI, PRADEEP SRIVASTAVA* and ASHA GUPTA**

Manipur Remote Sensing Applications Centre, Manipur, India.

**Deptt. of Limnology, Bharkhatullah University, Bhopal, India.*

***Dept. of Life Science, Manipur University, Imphal, India.*

***e-mail : anjalika_22000@yahoo.co.in*

Abstract

Loktak Lake, the largest freshwater lake in North East India is regarded as a wetland of International importance based on its unique biodiversity and socio-economic importance. However the lake is placed under the Montreaux Record in 1992 indicating that priority is to be given for conservation and management of the lake.

Using IRS-IC, IRS-ID, PAN data and IKONOS, a detailed study of the catchment area of this important Ramsar Site has been carried out. Different thematic maps are prepared at 1:25,000 scale by using merged data from PAN and IRS-LISS IV image. Land use data generated by this study helps in identification of areas where immediate attention has to be taken and enables in formulation of various management plans to restore this wetland. Visual and digital analysis techniques in GIS environment were used to prepare the thematic maps. Digital Elevation model of this catchment area is prepared to study other parameters due to construction of Ithai barrage. GPS reading in ground is converted into point coverage in GIS for verification of certain doubtful areas.

Key words : Loktak lake, thematic maps, GIS, GPS, DEM

सारांश

लोकटक झील उत्तर पूर्वी भारत में मीठे जल की विशालतम झील है जो अपनी अद्वितीय जैव विविधता तथा सामाजिक और आर्थिक महत्व के कारण अंतर्राष्ट्रीय महत्व की आर्द्र भूमि के रूप में मान्य है। उक्त झील को 1992 मे "मॉट्रियो रिकार्ड" में रख कर यह इगित किया गया है कि इसके सरक्षण तथा प्रबंधन को प्राथमिकता प्रदान की जानी चाहिये।

इस महत्वपूर्ण "रामसार स्थल" के जलग्रहण क्षेत्र का विस्तृत अध्ययन आई आर.एस.–आई सी., आई.आर.एस –आई.डी. पैन सूच्य और इकोनोस द्वारा किया गया है। पैन तथा आई.आर.–एस.लिस IV के विलनीय सूच्यो के आधार पर 1:25000 माप पर विभिन्न वर्ण्य–विषयक मानचित्र बनाये गये है। इस अध्ययन से उत्पन्न किये गये भूमि प्रयोग सूच्यो की मदद से उन स्थानों का अभिनिर्धारण किया गया जहॉ तात्कालिक ध्यान देने की और इस आर्द्र भूमि का जीर्णोद्धार करने हेतु विभिन्न प्रबधन योजनाओं के निर्माण को पूरा करने की आवश्यकता है। उक्त वर्ण्य विषयक मानचित्रों के बनाने मे जी आई एस. पर्यावरण में अवलोकनीय तथा अंकीय विश्लेषण तकनीक का प्रयोग किया गया है। 'इथाई बॉध', के निर्माण के कारण दूसरे पैरामीटरो के अध्ययन हेतु इस जलग्रहण क्षेत्र का अकीय उन्नयन मॉडल तैयार किया गया है। कुछ संदिग्ध क्षेत्रों के सत्यापन हेतु भूमि में जी.पी.एस पाठ्याक को जी.आई एस. मे बिन्दूय–क्षेत्र मे परिणित किया गया है।

सांकेतिक शब्द : लोकटक झील, वर्ण्य विषयक मानचित्र, जी आई एस, जी पीस, डी ई एम

Introduction

Manipur, the eastern most state of India lying $92^0 59'$E to $94^0 45'$E longitude and $23^0 50'$N to $25^0 41'$N latitude, straddling the international border between India and Myanmar, has a peculiar situation in the eastern Himalayas and watershed area of the great river basin systems the Brahmaputra and the Irawady. It is blessed with an enormously rich heritage of wetlands. Topographically the valley is surrounded by seven ranges of hills. Thus the wetlands in Manipur are mostly found in the valley area and are known by the generic name Pat (pronounced as paat).The surrounding hill districts are also replete with many kinds of large and small wetlands[1]

The pats of Manipur are known to have their own life-span and hydrologic characteristics related to the evolving geo-physical character of land itself. In the beginning of the 20^{th} century there were nearly 500

Table 1 - Data source

Sl. No.	Satellite Data	Path	Row	Date
1.	IRS-1B LISS-II	14	50	March, 1994
2.	IRS-1D LISS-III	113	54	Dec. 2003, Jan.2004, Feb.2001
3.	IRS-1D LISS-III	113	54	April , 2000, Jan.2002
4.	IRS-1C LISS-III	113	54	March, 1994
5.	LANDSAT -TM	-	-	1994
6.	SPOT MLA	-	-	1989, 1999
7.	PAN	113	54	Dec. 2003
8.	IKONOS (1m resolution)	-	-	Oct. 2002, Dec 2003

Table 2 - Land use in catchment area (2004)

Sl. No.	Land Use classes	AREA (IN HA)
1.	Built up land	15448
2.	Agriculture land	37055
3.	Dense forest	3100
4.	Open forest	7646
5.	Degraded forest	3514
6.	Scrub forest	6042
7.	Shifting cultivation- abondoned	1093
8.	Shifting cultivation- current	718
9.	Aquaponds/ waterbodies	2331
10.	Marshy / swampy land	509
11.	Hill / hillocks	705
12.	Wetland	25839
13.	Total	104000

Table 3 - Structural components of wetland area (2004)

Sl. No.	Habitat type/ zone	Area (in Ha)
1.	Open Water	2634
2.	Dense Phum	9176
3.	Moderate Phum	1058
4.	Sparse phum	1744
5.	Aquaponds	6911
6.	Agriculture	32
7.	Island with vegetation	288
8.	Island without vegetation	66
9.	Settlement	80
10.	Phum Ring area	3841
	TOTAL	25830

pats in the Manipur valley, covering a large portion of its area. Loktak lake after acclaiming Ramsar site is well known internationally. Apart from Loktak other well-known pats of Manipur are Ikop pat, Pumlen pat, Waithou pat, Ngakra pat and Loushi pat.

Loktak lake is the largest freshwater wetland in North-eastern region of India and is situated between 24^{o} 25' to 24^{o}42' N latitudes and 93^{0} 46' to 93^{0}55'E longitudes (Fig. 1-A). This lake was designated as wetland of International Importance under Ramsar Convention in 1990 because of its biological richness where naturally occurring phumdis (floating vegetation) covers the lake extensively and is a specialized habitat for many biotas besides being useful to the local people in many ways (Fig. 1-B). The Keibul Lamjao National Park in the southern part of the lake is also a unique floating wildlife reserve and the natural home of the endangered Manipur brow antlered deer, Sangai. Deforestation and shifting cultivation in the catchment has accelerated the process of soil erosion resulting in the lake shrinkage. The nutrients from catchment area and domestic sewage from Imphal city carried by the river Nambul are discharged into the lake which is another major problem of the lake[2]. All these activities have direct bearing on ecological stability of the lake.

There are a variety of modern techniques that can be integrated to make data acquisition and analysis

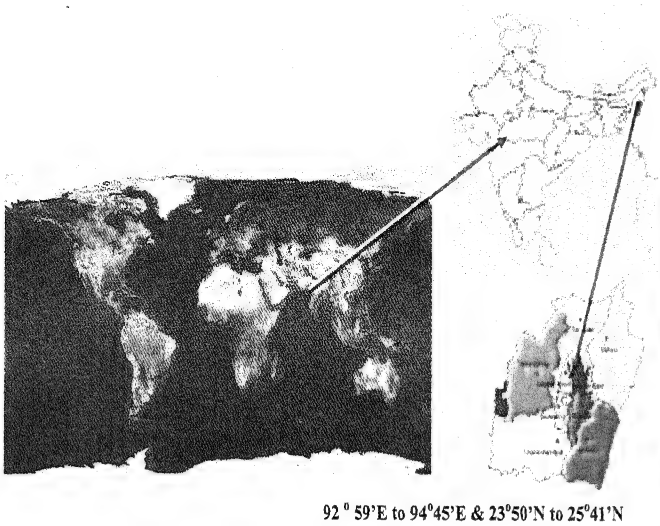


Fig. 1A - Location of Loktak lake

Fig. 1B - A view of Loktak lake with small islands.

of data easier and quicker. Remote sensing has emerged as a powerful tool for mapping and monitoring of natural resources[3]. In the specific context of its synoptic, multispectral and repetitive nature, this technology is extremely useful for providing an uptodate wetland information specially regarding its water spread, water quality and their seasonal variation.

The operational application of remote sensing technologies to lake monitoring have been reported in literature which discusses the use of the data derived from remote sensing to study and predicts catchment phenomena which affect quality of lake water, thus remote sensing products are quantitatively self-consistent and have a certified accuracy[3].

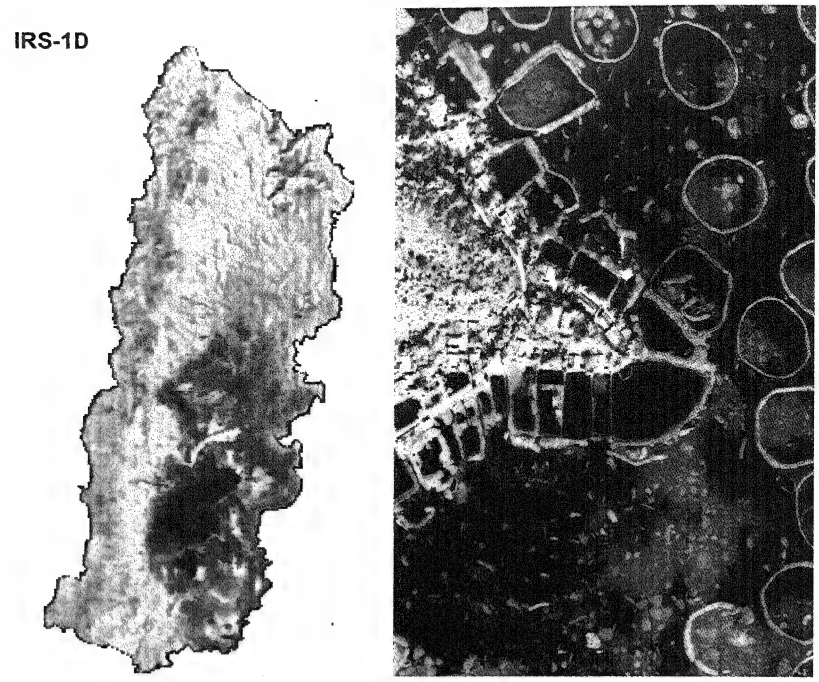
Land use and land cover analysis play an important role in issues related to catchment treatment and management. Remote Sensing and Geographic Information System (GIS) technique aid in judicious land use planning for sustainable development of an ecosystem. Many studies have been carried out to suggest soil and water conservation measures and alternate uses at catchment level through GIS. Catchment management is the process of formulation and carrying out a course of action involving modification of the natural system to achieve specific objectives. The judicious use of land and water resources in a catchment is pre-requisite for sustainable development of the lake ecosystem. Remote Sensing and GIS techniques have emerged as powerful tools aiding management programs.

Study Area

Loktak has direct catchment of 1040 sq. km and falls under the sub-basin of the Manipur river. The catchment area lies between 24°24' to 24°57' N latitude to 93°40' to 93°58' E longitude. The topography is undulating having elevation of 780 m at the foothills adjoining the central valley and about 2068 m at highest peak. There are about 98 villages with a total population of 21,334 (1991 census).

The presence of Ithai Barrage, a multipurpose project for generation of hydel- power and irrigation which was commissioned in 1983 at Ithai at the southern nearest tip of Loktak, has brought about drastic hydrological changes.

Loktak catchment area comprises the elongated hilly terrain of various altitudes along with isolated hillocks, plains and marshy lands. Altitude of elongated hill ranges and isolated hillocks varies between



SATELLITE IMAGE OF CATCHMENT AREA

IKONOS DATA SHOWING PHUM RINGS INSIDE LOKTAK LAKE

Fig. 2 - Satellite Image (IRS-1D and IKONOS) of the study area

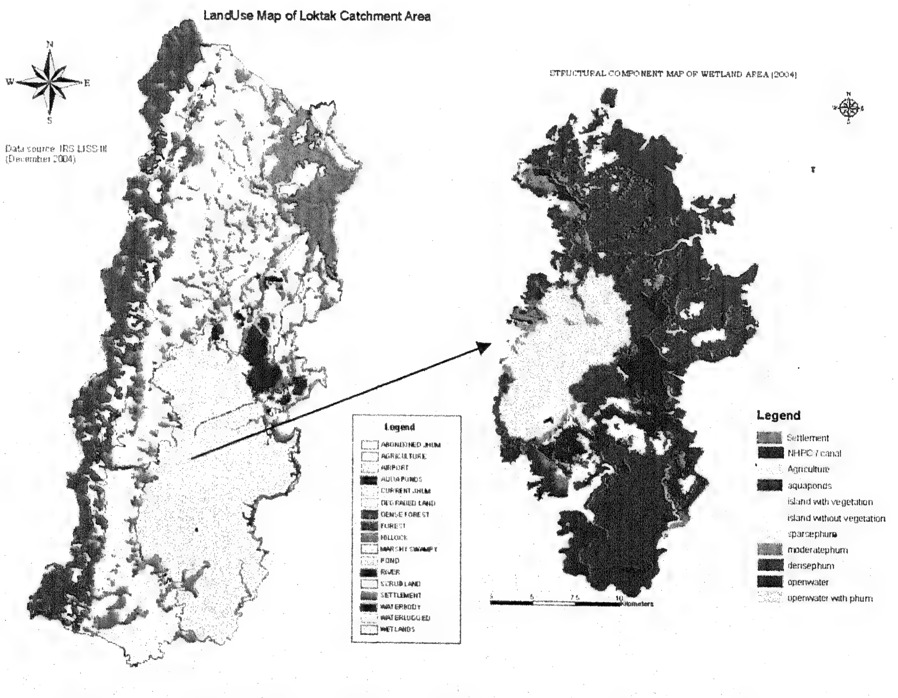


Fig. 3 - Land use map of Loktak catchment with wetland area 2004

820 to 2068 meter and 760 to 1100 meter above mean sea level respectively.

The rock formations in the catchment area are cretaceous limestone, the Disang with Serpentinites (Lower to Middle Eocene-Upper cretaceous), the Surmas and the Thipams (Miocene). Surma group occurs in the lower reaches of hills where as the Disang and Thipam groups occur in high reaches of hills. Disang formation comprises grey sandstone-grit-conglomerate limestone sequences intruded by serpentinites containing minor amounts of enstalite, chromite, amphiboles and magnetite. The Surma and Thipam groups are represented by argillaceous and arneceous sequence respectively.

Objectives

The present study lays the foundation for developing wetland conservation models using remote sensing and geo-spatial technologies. Some of the detailed objectives of the study area:

- Creation of temporal spatial database using satellite data[4] for catchments (1995, 2000 and 2004-05) and structural components/ habitat types of wetlands
- Generation of Land Capability map for the catchment area for long term and short term management plan such as formulation of soil conservation plan to check soil erosion and subsequent silting up of Loktak lake.
- Collection, integration and modeling for suggesting sustainable management solution for conservation of Loktak wetland.

Data Used/Sources

The database of this catchment study consists of primary, secondary and integrated database of spatial and non-spatial data on different components of the catchment. Census data of 1991 and 2001 is used for socio-economic studies of the hill and valley region. Table 1 gives the list of satellite data used.

Methodology/Thematic Maps

Visual and digital image interpretation techniques were used to prepare thematic maps on 1:50,000 for 1990, 1995, 2000 using 23.5 meter resolution data of IRS-1C, 1D and 1:25,000 for 2004-05 using high resolution data like IKONOS (Fig 2), for some area and merge data of 2.5 meter resolution using LISS-III and PAN data. Global Positioning System (GPS) was used for verification of certain area which was doubtful at satellite image during ground survey. The reading was taken as co-ordinates of the ground location which was converted into point coverage in GIS. Identification of village location, and other secondary data was taken by GPS. Secondary data for socio-economic study are also incorporated. The thematic maps are :

- Land use/cover
- Hydrogeomorphology
- Drainage
- Road network
- Settlements.
- Slope

A. Land Use/Cover :

Information on Land use/cover pattern, especially the extent and spatial distribution is a pre-requisite to derive information on temporal changes. The land use/cover information helps to identify areas where immediate attention has to be taken for reviving various landscape elements. The present status of land use (Table 2) in the catchment is useful for identifying locations for taking up soil conservation measures by involving village communities, for minimizing land degradation. Land use classification for 2004-05 is based on guidelines of 'Biodiversity Conservation in Wetland Project' by Space Applications Centre, ISRO, Ahmedabad[5].

The land use class of wetland is further classified by preparing a structural component map of Loktak wetland area which shows various classes of phums, agriculture land, islands and aquaponds etc. In the present study SOI topography map of 1970 was used as the base to delineate water spread and demarcate wetland boundary. IKONOS data was used for preparation of the structural component map of 2004-05 (Fig. 3, Table 3).

B. Hydrogeomorphology :

Information on landforms is an important input for land management and soil mapping. The aspects

of morphology, morphogenesis, morpho chronology and morphometry are vital inputs in preparation of geomorphologic maps. The geomorphic units are delineated based on the basis of image characteristics like tone, texture, shape, colour, associations etc. (Fig. 4A).

C. Drainage/Watershed :

A drainage map of the study area was prepared using satellite data in conjunction with SOI topography maps. Most of the streams originate from the hill ranges to the west of the lake and discharge water directly into Loktak lake. Some of the major streams include Nambul, Nambol, Thongjaorok, Awang Kujairok. Awang Kharok, Ningthoukhong, Potsangbam, Oinam, Keinau and Irulok contributing significant silt during rainy season to the lake. In all 12 micro-watershed were demarcated and they have been given nomenclature according to the standard of All India Soil and Land Use Surveys (AIS and LUS) of the Ministry of Agriculture[6]. (Fig. 4B).

D. Road Network and Settlements :

The road transport network is one of the major criteria for studying and analyzing the socio-economic problems of a certain area and for assessment of impact on the wetland. In the present study, there are three types of roads as national highways, village roads and other which may include footpaths etc. The total length of national highways is 59.652Km, village roads 723.243 km and others 234.5 km. (Fig. 4C).

E. Slope :

Information on slope is vital for suggesting actions related to restoration plans of landscape. This information is useful for suggesting checking of soil erosion and drainage related measures. The slope map has been prepared as per IMSD guidelines. Using this information Digital elevation model has been generated using 20 meter contour interval. This model can be used for estimating the area inundated due to the construction of a dam at Ithai at various levels of water. (Fig 5A and Fig 5B)

Results, Discussion and Conclusion

i. Spatial Analysis : Land Use Change detection

Multi-temporal satellite data have been used for studying land use practices over a period of fifteen years in the catchment of Loktak lake (Table 4). It has been found that there is an increase in the built up area and also decrease in scrub forest. There was increase in dense forest from 1990 to 2002. This may be due to some of the activities of afforestation program taken up by LDA for catchment treatment but again this has declined in 2004-05. There was an increase in open forest area during 2004 and decrease in degraded forest which shows that deforestation activities have become less and natural regeneration is going on in the catchment area.

There has been an increase in the water spread in the water bodies/aqua-ponds. This is mainly due to conversion of agriculture and marshy/swampy land into aquaponds. There is rapid increase in fishing activities in the state of Manipur. Annual fish yields from these aquaponds have also increased drastically.

ii. Spatial analysis: Land Capability

Land capability classification is the grouping of soil which is mainly based on i) inherent soil characteristics ii) external land features and iii) environmental factors that limit the use of land. Classification of soil units into capability groupings enables one to get a picture of i) the hazards of the soil to various factors which cause soil damage, deterioration or lowering in fertility and, ii) its potentiality for production.

The grouping of composite units (land use, slope and soil) based upon various individual external factors and inherent soil characteristics suggested by soil survey manual[6] have been followed. A land capability map showing capability classes (Fig 4 D) and classes are given in Table 5.

There has been an increase in the water spread in the water bodies/ aqua-ponds. This is mainly due to conversion of agriculture and marshy/ swampy land into aquaponds. There is rapid increase in fishing activities in the state of Manipur and annual fish yields from these aquaponds have also increased drastically.

As per report on land capability of Loktak catchment area of Loktak lake of Manipur, published by National Bureau of Soil Survey and Land Use Planning, Nagpur, the following table gives some of the recommended and suggested different capability units (Table 6). The Land capability classes are generated by integrating several thematic maps in GIS.

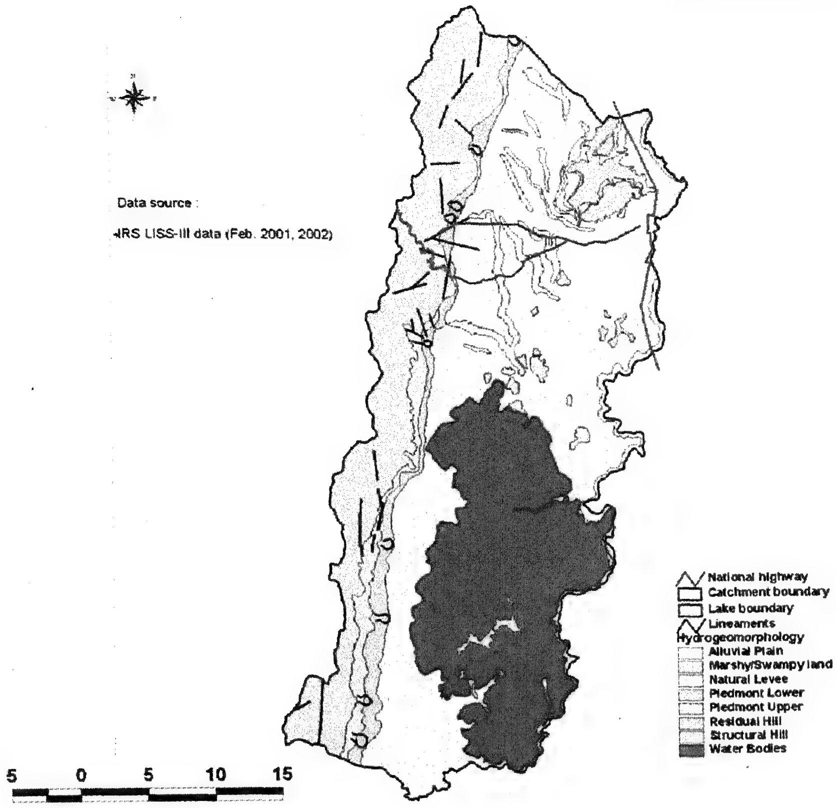


Fig. 4A - Different thematic maps of Loktak catchment area showing hydrogeomorphology

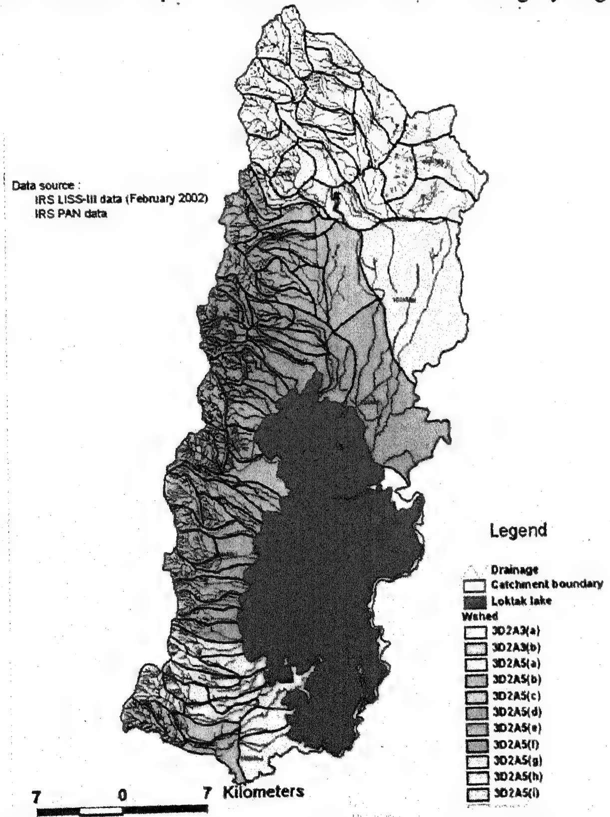


Fig. 4B - Different thematic maps of Loktak catchment area showing drainage and watershed boundary

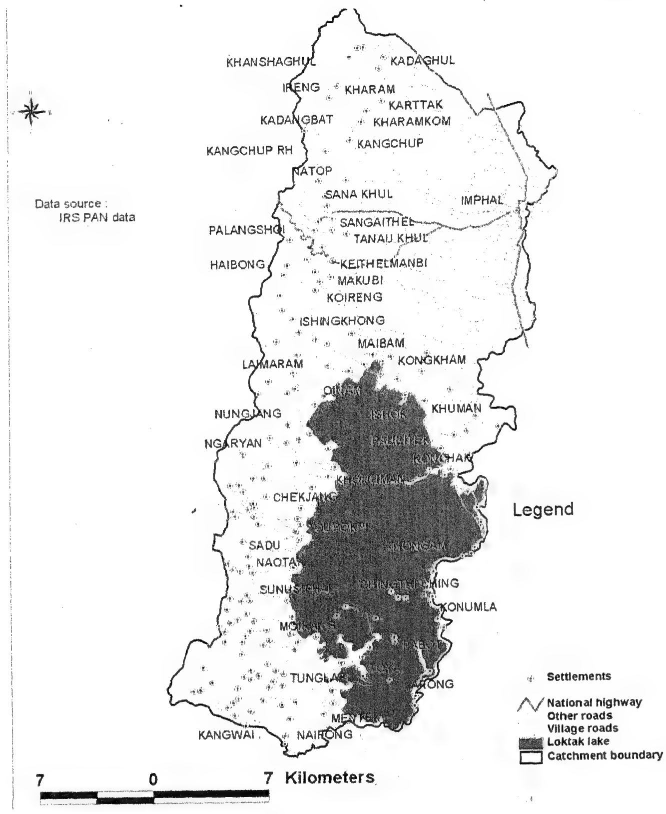


Fig. 4C - Different thematic maps of Loktak catchment area showing settlement and transport network

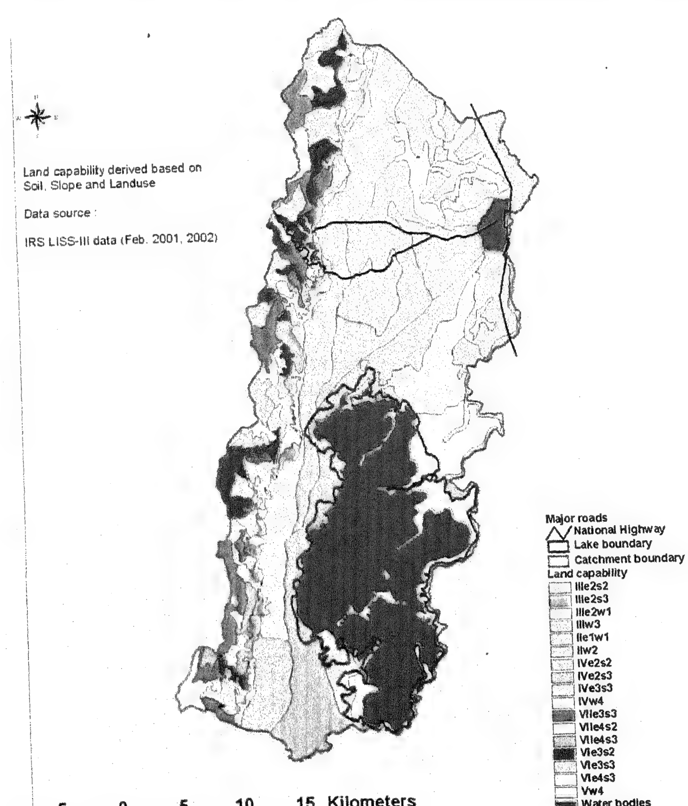


Fig. 4D - Different thematic maps of Loktak catchment area showing land capability

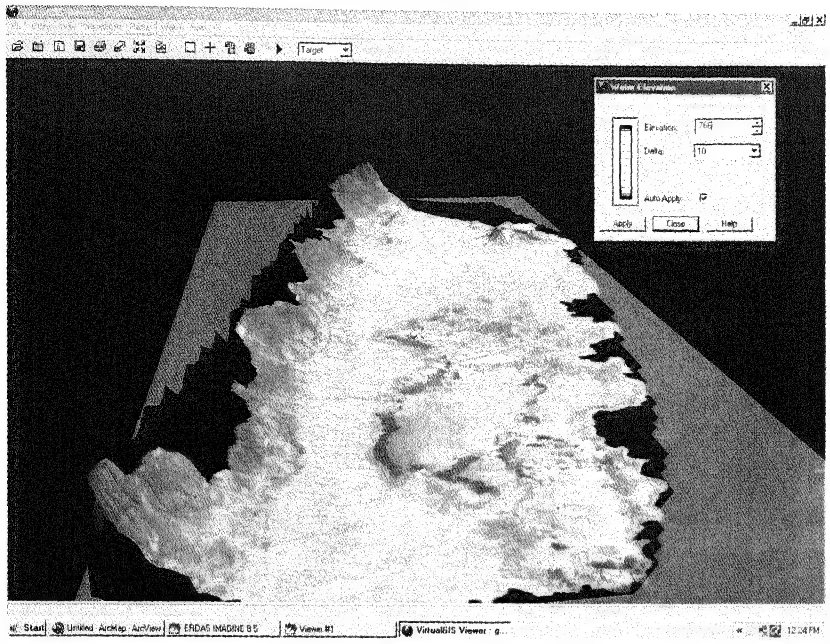


Fig 5A

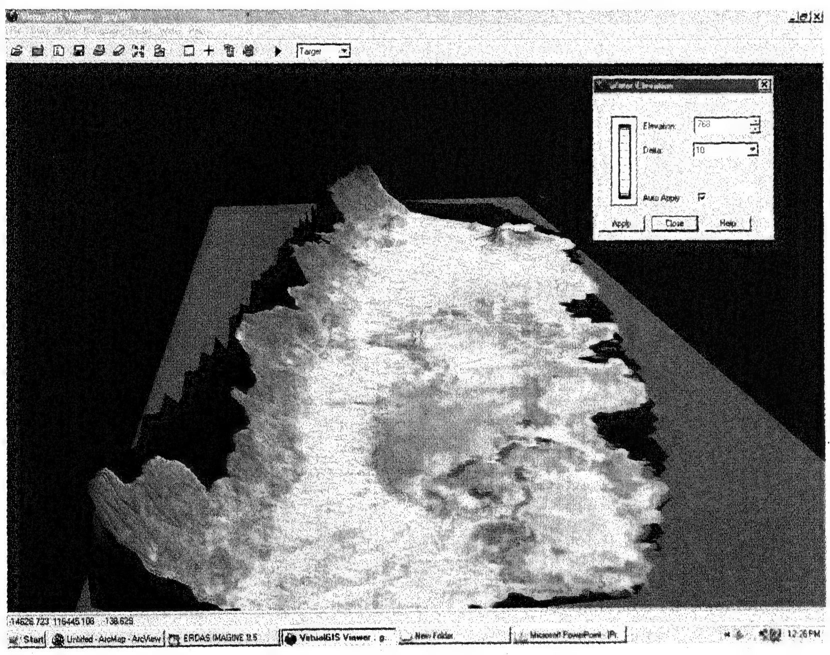


Fig 5B

Fig. 5 - Digital elevation modelling of Loktak catchment area A. Showing waterspread at 766 MMSL B. Showing waterspread at 768 MMSL

Table 4 - Land use : Loktak catchment area

Sl No.	Land use classes	Area (in Ha)/Years		
		1990	1995	2002
1.	Built up land	14558	14608	15359
2.	Agriculture land	37735	36572	3645
3.	Dense forest	1493	1153	4541
4.	Degraded forest	9312	10716	9585
5.	Scrub forest	9732	9777	7330
6.	Shifting cultivation	3131	2369	2127
7.	Marshy / swampy land	631	419	84
8.	Grassland/Grazing Land	391	304	141
9.	Hill / hillocks	755	755	755
10.	Aquaponds/ waterbodies	974	1988	2471
11.	Wetlands	25312	25339	25154
	TOTAL	104000	104000	104000

Table 5 - Land capability classes : Loktak catchment

Sl.No.	Land capability class	Area (Ha.)
1.	IIIe2s2	1800.06
2.	IIIe2s3	1063.61
3.	IIIe2w1	3062.82
4.	IIIw3	10446.89
5.	IIe1w1	10928.59
6.	IIw2	8637.92
7.	IVe2s2	937.40
8.	IVe2s3	1572.45
9.	IVe3s3	3586.77
10.	IVw4	5333.07
11.	VIIe3s3	3850.49
12.	VIIe4s2	811.79
13.	VIIe4s3	3077.94
14.	VIe3s2	3518.89
15.	VIIe3s3	3631.12
16.	VIe4s3	1234.08
17.	Vw4	5046.54
18.	Waterbody	20142.11
19.	Settlements	15315.82
	Total	103998.36

Use of digital map processing in analyzing land use pattern of Loktak catchment revealed that the agricultural activities constitute the major geographical part of the catchment. With practice of jhum cultivation in hill areas, proper development strategies can be chalked out for minimizing erosion hazards. The proliferation of phumdis in Loktak lake due to various reasons has reduced the water holding capacity of the lake with a decline in fish yield which earlier constituted 60% of the total fish production from Manipur. The inundation of agricultural fields in the periphery of Loktak lake is responsible for change in the profession of erstwhile farmers . Increase in water spread area because of heavy siltation of Loktak lake has been responsible for the creation of more and more aquaponds for fishing purpose. The increase in dense forest cover coupled with decrease in scrub forest implies that afforestation activities and protection effort by tribal communities have paved way for the natural regeneration in the hill catchment. For various land capability classes generated by integrating several thematic maps in GIS, different land uses have been recommended and suggested which forms an important component of catchment area treatment for integrated management.

Thus, the results obtained so far confirm the benefits expected from the use of satellite data for model parameterization. Derivation of parameter information

Table 6 - Recommendation and suggested land use in different capability units.

Land Capability Grouping (units) and Locations	Major Soil Constraints	Recommendations/ Suggested Land Use
1	2	3
VIIe4s3 Mostly in high hills covering Ireng, Nungjang, Troglobilok, Churachandpur, and Liklai.	* Very steep slopes * Stoniness * Very severe erosion hazard * Very strong soil acidity * Low exchange capacity and base status * Shifting cultivation and land slides	Rill and gully erosion control by putting small check dams at frequent intervals; plantation of forest species in open areas and proper soil conservation of existing forest.
VIIe4s2 In high hills covering Sinda Bagan Leriong, Tairen Pokpi. Churachandpur Khoupum.	* Steep to very steep slopes * Very severe erosion hazard * Very strong soil acidity * Low exchange capacity * Low base status * Jhum cultivation	Gully erosion control with check dams, restriction of felling, firing, grazing etc., plantation of forest species with proper soil conservation measures.
VIIe3s3 Mostly in hilly terrain covering Kangchup R.F., Kangchup Chiru RF. Bherum, Khonga Khul, Mairangching Khunou, Churachandpur.	* Moderately steep to very steep slopes * Severe erosion hazard * Stoniness * Very strong soil acidity * Low CEC and base status * Shifting cultivation	Contour terracing to protect the terraces; restriction of free grazing, firing, forest cutting; plantation of forest species are suited in this region.
Vie4s3 Mostly in hilly terrain covering Kangchup, Natokon, Lamdan, Kholrok and Parengba.	* Moderately steep to steep slopes * Stoniness * Very severe erosion * Very strong soil acidity * Low exchange capacity * Shifting cultivation and land slides	Preservation of existing forest from firing, tree cutting, jhuming, grazing etc. and plantation of suitable forest species; provision for diversion channel and vegetative waterways. Contour terracing by putting stones to protect the terraces and gully erosion control.
Vie3s3 In hilly terrain covering , Sungang, Ireng, Bherum, Tairen Pokpi, Mairangching Khunou, Laipham, Gothol.	* Moderately steep to steep slopes * Stoniness * Severe erosion * Very strong soil acidity * Low CEC and base status * Jhum cultivation	Afforestation of open areas, protection from jhuming, and grazing. Provision for diversion channel vegetative waterways and contour terracing.
Vic3s2 Mostly in hilly terrain covering Kangchup Chiru, Kangchup	* Moderately steep slopes * Severe erosion	Provision of diversion channel and vegetation waterways. Terracing by putting

Continued......

Land Capability Grouping (units) & Locations	Major Soil Constraints	Recommendations/ Suggested Land Use
1	2	3
Makhon, Natop, Tairn Pokpi, Ngariyan.	* Very strong soil acidity * Low base status * Shifting cultivation	the stones to protect the terraces; preservation for existing forest from tree cutting, firing, grazing etc. along with agro silvi pastoral programme.
Vw4		
In very low lying areas covering Charaibung, Khonumla and Karang.	* Very severe limitation of water stagnation/ flooding * High water table * Very poor drainage	May be used for pisciculture and cultivation of waterchestnut with proper agronomic practices.
IVe3s3		
Mostly in foot hills and isolated hillocks covering Kangchup, Meirang Ching Khunou, Mashemjang.	* Moderately steep to very steep slopes * Stoniness * Very strong soil acidity * Low CEC and base status * Jhum cultivation	Maintenance of existing terraces by cover crops and plantation of perennial grass of legume variety; selected areas may be brought under fruit trees and other orchard crops with proper soil conservation and agronomic practices.
IVe2s3		
In foot hills covering Bijan Tampok, Lonphal, Laching Manbi and Mairangching Khunou.	* Moderately steep slopes * Stoniness * Very strong soil acidity * Moderate erosion hazard. * Low CEC and base status * Shifting cultivation	Plantation of economical species on the ridges of the terraces, horticultural crops/orchard crops in the side slopes with proper conservation measures.
IVe2s2		
Mostly in foot hills covering Bijang Tampok, Woynan, Isham Khuman and Mairangching Khunou.	* Moderately steep slopes * Moderate erosion hazard. * Very strong soil acidity * Low base status and exchange capacity.	Proper maintenance of existing terraces, provision for vegetative waterways, cultivation of plantation crops along with agro forestry.
IVw4		
In low lying plains covering Thinnuggai, Ishok and Naurem.	* Very severe water stagnation * Very poor drainage	Cultivation of suitable varieties of paddy along with pisciculture; improvement of drainage.
IIIe2s3		
Mostly in foot hills covering Khonga Khul, Chingphel, Kelthenmanbi, Rharyeng.	* Moderate slopes * Moderate erosion * Stoniness * Strong soil acidity * Low CEC	Proper soil conservation measures may help in growing various horticultural and plantation crops.

Continued......

Land Capability Grouping (units) & Locations	Major Soil Constraints	Recommendations/ Suggested Land Use
1	2	3
IIIe2s2 In lower slopes of foot hills covering Rharyeng Khunoi, Parengba, Bungte Chiru.	* Moderate slopes * Moderate erosion * Strong soil acidity * Low CEC and base status	A variety of horticultural and plantation crops can be grown with proper soil and water conservation practices.
IIIe2w1 Mostly in gently sloping plains covering Khongathel, Koirentak Khunou.	* Moderate erosion * Slight stagnation of water * Imperfect drainage.	These lands are suitable for rice. Selective crops can be grown during winter season.
IIIw3 Mostly in level to very sloping plains covering Khabi, Kamong, Awangjiri, Oksong-bung, Kwasiphai.	* Severe limitation of water stagnation * Poor drainage	These lands require drainage improvement and some selective crops can be grown during winter season.
IIe1w1 Mostly in very gently sloping plains covering Phaiyeng, Tairen Pokpi.	* Slight stagnation of water * Imperfect drainage	These lands are suitable for rice. A number of crops can be grown during winter season.
IIw2 Mostly in very gently sloping to nearly level plains covering Khongarthel.	* Moderate stagnation of water * Imperfect drainage.	These lands are suitable for cultivation of kharif rice. A number of crops can be grown during winter season.

of the catchment character can be done by means of integrated remote sensing techniques and Geographical Information System (GIS) which may support sustainable water resource management programme of Loktak Lake therefore integrated catchment modeling may help in solving multiple issues related to catchment area treatment.

Acknowledgement

The authors would like to acknowledge Dr. Ajai,Group Director, Dr. J.K. Garg, Dr. T.S. Singh and J.G. Patel of Space Applications Centre, ISRO, Department of Space, Government of India, Ahmedabad for the immense help they rendered.

References

1. Singh NS, Singh NR, Garg JK, Murthy TVR. Wetland of Manipur, Ahmedabad: MARSAC and Space Application Centre, 1999. pp. 26-27.
2. Trisal CL, Manihar T. Management of Phumdis in Loktak Lake. Proceedings of symposium on Management of Phumdis in Loktak Lake, 2002, 22-24 January, Imphal, Manipur.
3. Brivio PA, Giardino C, Zilioli E. Validation of satellite data for quality assurance in lake monitoring applications. *The Sci Total Env* 2001; **268** : 3-18.
4. Anonymous. Wetland Mapping Project- Implementation Plan. Ahmedabad: Space Application Centre, ISRO, 1994.
5. Anonymous. Biodiversity Conservation in Wetland. Standards and Technical Guidelines, Ahmedabad : Space Applications Centre, ISRO, 2004.
6. Anonymous. Land Capability of Loktak Catchment Area of Loktak Lake, Nagpur: National Bureau of Soil Survey and Land Use Planning, 2002.

Proc. Nat. Acad. Sci. India, Sect. B, Vol. 78, Spl. Issue, 2008

Modeling the non-point source pollution load in the catchment using remote sensing and GIS: A case study of Hokersar wetland, Kashmir

AAMIR BIN MASOOD, HIMAYOON HASSAN*, ASHOK K. PANDIT** and RAVINDER KUMAR

Dept. of Environmental Science, Center of Research for Development (CORD), University of Kashmir, Srinagar-190006, India.

**Dept. of Geography and Regional Development, University of Kashmir, Srinagar-190006, India.*

***e-mail : prof_akpandit@yahoo.co.in.*

Abstract

The water quality of Hokersar wetland has deteriorated considerably in the last few decades due to eutrophication. Remote sensing and GIS have been involved in water quality assessment since decades. In the present study, PLOAD (Pollution Load) model with a geographic information system (GIS) interface was used to estimate pollutant levels generated from various land use activities in the watersheds and carried into the wetland. The datasets used in the study included Landsat image, 90 m digital elevation model, ancillary data, pollutant loading rate data (lb/ac/yr) and field data. The PLOAD model gives the pollutant loadings by watershed (lb/yr) and watershed area (lb/ac/yr). The export coefficient values for various pollutants like biochemical oxygen demand, total suspended and dissolved solids, ammonia, total phosphorus and total nitrogen were collected from the literature. The land use / land cover map of the catchment depicted 12 land use classes, whereas the watershed map depicted 5 watersheds in the wetland catchment. Among the 5 watersheds, watersheds number 1 and 5 witnessed the highest annual loads of all the pollutants except TSS. The pollutants are contributing towards eutrophication of this beautiful wetland. It is concluded that these watersheds in the catchment of the Hokersar need to be managed based on their contribution towards the cultural eutrophication of the wetland.

Key words : eutrophication, watershed, landsat, digital elevation model, land use, land cover.

सारांश

पिछले कुछएक दशको मे होकेरसर आर्द्र भूमि की जलीय गुणवत्ता का यूट्रेफिकेशन के कारण अध्यधिक ह्रास हुआ है। दशको से जल की गुणवत्ता के मूल्यांकन में दूरस्त संवेदन और जी.आई.एस. का उपयोग हो रहा है। प्रस्तुत अध्ययन में पनढाल पर विभिन्न भूमिपयोगी कार्यों द्वारा जिन्हे आर्द्र भूमि तक ले जाया गया हो, प्रदूषक स्तर का अनुमान एक अतरापृष्ठ भौगोलिक सूचना तंत्र के साथ प्रदूषण भार मॉडल द्वारा लगाया गया। उक्त अध्ययन में प्रयोग में लाये गये प्रमुख सूच्य–सघटक रहे है भूउपग्रहीय प्रतिबिब, 90 एम. अंक वृद्वीय मॉडल, अनुषगी सूच्य, प्रदूषक भरण सूच्य दर (lb/ac/yr) और क्षेत्रीय सूक्ष्य। प्रदूषण भार मॉडल पनढाल (lb/yr) और पनढाल क्षेत्र (lb/ac/yr) में प्रदूषक भरण का ज्ञान देता है। विभिन्न प्रदूषकों जैसे जैव रसायनिक आक्सीजन अर्हता, पूर्ण विस्थापित तथा विलयनीय ठोस, अमोनिया, पूर्ण फास्फोरस तथा पूर्ण नाइट्रोजन के निर्यातीय गुणाक मूल्य वाग्मय से इकट्ठा किये गये हैं। जलग्रहण क्षेत्र का भूमिप्रयोग/भू–मानचित्र 12 भूमि प्रयोग वर्ग, जबकि पनढाल मानचित्र आर्द्र–भूमि के जलग्रहण में 5 पनढाल दर्शाता है। इन 5 पनढालो मे पनढाल संख्या 1 और 5 टी.एस.एस. को छोडकर बाकी प्रदूषको का अति वार्षिक भार दर्शाते है। इस सुंदर आर्द्रभूमि के यूट्राफिकेशन मे प्रदूषकों का महत्वपूर्ण योगदान है। इस प्रकार यह निष्कर्ष निकलता है कि होकेरसर के जलग्रहण क्षेत्र में स्थित इन पनढालो का इस आर्द्र भूमि के सांस्कृतिक यूट्रॉफिकेशन की भूमिका में प्रबंधकीय योगदान बनाये रखने की आवश्यकता है।

सांकेतिक शब्द : यूट्राफिकेशन, पनढाल, भूउपग्रहीय, अंक वृद्वीय मॉडल, भूमि प्रयोग, भू–विस्तार।

Introduction

Wetlands, the transitional systems between purely terrestrial and aquatic ones, are the most sensitive ecotones claiming a large area in Kashmir. One such wetland is Hokersar, 'the Queen Wetland', which alone harbours a large proportion of the total population of migratory birds that visit the Kashmir valley during winter from the palaearctic region, exrending from Central Asia to North Europe, besides providing breeding ground to a host of resident birds and non-resident summer visitors from Indian plains. During the past few decades, land use changes in the catchment, disposal of sewage from the adjoining settlements, encroachments for housing, and development of floating gardens for agricultural purposes, besides soil erosion are greatly responsible not only for deterioration of the lake's environment but also for its shrinking size[1, 2, 3, 4,5].

Apart from the conventional techniques, remote sensing and geographic information system (GIS) modeling have been widely used in water quality studies. Various GIS models have been developed and applied on streams, lakes and estuaries[6, 7, 8]. Modeling of non-point source pollution is still in its early stages. However, model such as the Unites States Environmental Protection Agency's (USEPA) BASINS (Better Assessment Science Integrating Point and Non-point Sources) is the beginning to bring a uniform approach[9]. BASINS is a multi-purpose environmental analysis system for use by regional, state, and local agencies in performing watershed and water quality based studies.

In the present study, one of the models of BASINS, PLOAD (Pollution Load), a GIS-based model, was used to estimate the annual pollutant loadings coming into the wetland from the watersheds within the catchment. The main objective of the study was to define pollutant levels coming from various land uses in the catchment into the wetland. This study assumes great significance keeping in view the ecological and aesthetic importance of the wetland. Because heavy pollutant loads may adversely affect the wetland functions, estimating the increase in pollutant load due to land use changes in the catchment may be of interest for regulatory and planning purposes.

Study area

The study area is the Hokersar wetland catchment (Fig. 1), which is situated between the geographical coordinates of 33°41′ - 34°07′ N latitude and 74°27′ - 74°55′ E longitude. The catchment has an area of 695 km².

The Hokersar wetland is a permanent shallow wetland, protected wildlife reserve, located about 10 km west of Srinagar city at an altitude of 1584m (a.m.s.l.) on Srinagar-Baramulla National Highway (NH-1A), harbouring about 0.5 million migratory waterfowl during winter. The Hokersar wetland is having both inflow and outflow channels. The main source is the Doodhganga Nallah that enters into the lake on the eastern side after originating from Sang-e-Safed high up in the Pir Panjal mountains. The water drains out through an outlet channel having a needle gate to regulate the water level during winter. The present area of the wetland is about 7.5 km^2 compared to its original area of 13.5 km^2 at the turn of twentieth century. Hokersar alone harbours about 80%-90% of the total population of migratory birds that visit the Kashmir valley during winter from the palaearctic region, exrending from Central Asia to North Europe, besides providing breeding ground to a host of resident birds and non-resident summer visitors from Indian plains.

The wetland catchment broadens in the northeast direction. The catchment exhibits a varied topography with altitudinal range of 1574-4694 meters. The climate of the area is sub-humid temperate. The average monthly temperature is 11°C and the average annual rainfall is 650 mm.

Data sources

In the study, a variety of data sources including Landsat ETM+ satellite image acquired on 30 September 2001, 90 m digital elevation model (DEM) from Shuttle Radar Topography Mission (SRTM) (Fig. 2), ancillary data about the export coefficient values for various pollutants[10, 11, 12, 13] and ground truth data were used.

Methodology

The research applied an integrated approach by using remote sensing, simulation modeling and field data. The methodology is briefly discussed under the following headings :

Pollution Modeling

A GIS-based model PLOAD was used in this study. PLOAD is a simplified geospatial model developed by CH2M HILL USEPA[9] for calculating pollutant load from watersheds. PLOAD estimates non-point loads (NPS) of pollution on an annual average basis, for any user-specified pollutant. The user may calculate the NPS load using either the export coefficient or the EPA's Simple Method approach. The various requirements of the model include:

- Generation of land use/land cover map in a vector format.
- Watershed map of the area.
- Export coefficient values (in lb/ac/yr)

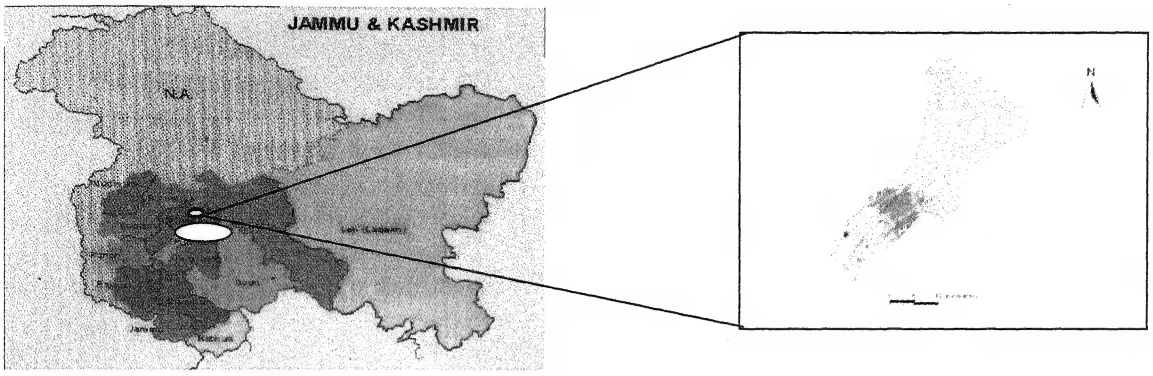


Fig. 1 - Location map of the study area.

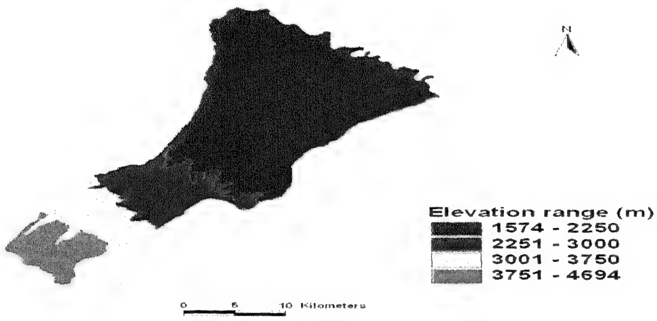


Fig. 2 - DEM of the wetland catchment.

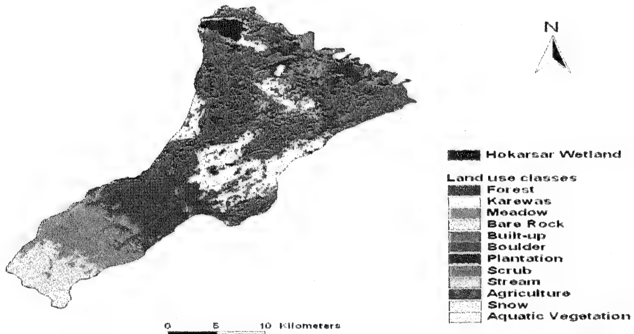


Fig. 3 - Land use / land cover map of the study area.

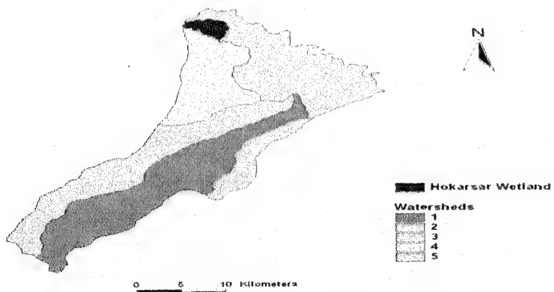


Fig. 4 - Watershed map of Hokersar catchment.

Optionally, best management practices (BMPs), which serve to reduce NPS loads, and point source loads may also be included in computing total watershed loads. Finally, there are several product alternatives that may be specified to show the NPS pollution results as maps and tabular lists.

Generating Model Input Parameters

Delineation of Catchment Area and Watersheds: A 90m DEM was used for topographic analysis. The topographic details were useful in understanding the distribuion of different land use classes in the area, as the terrain determines the spatial variability of the land use classes. It was used in the delineation of catchment and watersheds. The catchment area and the watersheds were identified from DEM and then digitized in GIS to a vector layer along with associated attribute database.

Image Processing and Land Use/Land Cover Classification: Before using the satellite imagery for classification, the image was pre-processed and processed in ERDAS Imagine. The image was geometrically corrected in ERDAS Imagine and referenced to Lat-Long coordinate system with WGS 84 datum. Different contrast enhancements were used to enhance the interpretability of the image.

To generate the LULC map of the study area, Landsat 7 ETM+ image with three channels of information was selected. Appropriate scene (area of the study) was clipped from the image. A false colour composite (FCC) having a band combination 4:3:2 (IR:R:G) was used. Supervised classification was carried out on the image using maximum likelihood classifier. Ground validation was carried out for all the land use classes identified in the study area. The necessary changes were incorporated and the final map was prepared.

An accuracy assessment of the classification was carried out taking random samples over the whole study area to cross validate the classification. By selecting random and field sampled ground truth data, 100 data points were collected and were utilized in the analysis.

Pollution Data and Export Coefficient Table: In the study, the data about the export coefficient values for various pollutants were taken from the literature [10, 11, 12, 13], and the resultant data was used in the generation of export coefficient table.

Model Simulations

PLOAD model was used to simulate the pollutant loads into the Hokersar wetland. Among GIS data, land use and watershed data were generated in the

Table 1 - Percentage-wise distribution of different land use classes

S.No.	Class Name	Area (km^2)	Percentage (%) Area
1.	Forest	87.53	12.58
2.	Karewas	76.45	10.99
3.	Meadow	43.66	6.27
4.	Bare rock	41.40	5.95
5.	Built-up	20.63	2.96
6.	Boulder	12.01	1.72
7.	Plantation	143.72	20.66
8.	Scrub	41.72	5.99
9.	Stream	7.64	1.09
10.	Agriculture	202.83	29.15
11.	Snow	8.31	1.19
12.	Aquatic vegetation	9.70	1.39
	TOTAL	695.6	100

present study. Best Management Practices (BMP) data being optional were not generated due to unavailability of data. Among tabular data, export coefficient table was generated. Impervious terrain factor data tables were not developed, since they are used only when using simple method for pollutant loading calculation, whereas export coefficient method was used in this study.

For calculating pollutant loading into the Hokersar wetland, export coefficient method was used, since the application of the simple method is limited to small drainage areas of less than one square mile. After the generation of all the required inputs, the PLOAD was executed and the modeling results showing the pollutant loading were represented as maps and tables.

Results

Land Use / Land Cover Map: 12 different land use classes viz. forest, karewas, meadow, bare rock, built-up, boulder, plantation, scrub, stream, agriculture, snow and aquatic vegetation were observed in the study area (Fig. 3). The overall classification accuracy was found to be 88.60% with overall Kappa statistics equal to 0.8690.

Agriculture dominates the study area covering 29.15 % of the total study area (Table 1). Plantation ranks second with 20.66 %, whereas forest comes next with 12.58 %. The least representative of the land use is stream covering just 1.09 % of the area.The land use map helped in having an understanding of various pollution loads coming from different points in the catchment, as the pollution load is directly related to the land use/land cover type.

Watershed Map: A total of 5 watersheds (Fig. 4; Table 2), viz. Doodhganga, south-eastern, Shaliganga, south-western and urban, were represented by the watershed map of the study area. The map forms an essential input to the model. Pollutant loadings in PLOAD are estimated by watershed and/or watershed area. Many water quality problems are best solved at the watershed level rather than at the level of an individual waterbody or discharger. It is important that a watershed approach be used to address water quality concerns because land-use decisions made in one area of a watershed will inevitably affect those living in another part of the watershed. Watershed data was then used in the model to get the pollution load for each watershed.

Table 2 - Watersheds in the Hokersar catchment

ID	Watershed Name	Area (km^2)	Dominant land use
1.	Doodhganga	201.15	Forest, meadow, karewas
2.	South-eastern	45.18	Karewas, plantation
3.	Shaliganga	161.57	Forest, meadow, plantation, agriculture
4.	South-western	107.81	Plantation, agriculture
5.	Urban	179.89	Agriculture, built-up, plantation, aquatic vegetation

Export Coefficient Table: Export coefficient table was generated from the export coefficient values (in lbs/ac/yr) collected from the literature. The values were obtained for Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Biochemical Oxygen Demand (BOD), Total Phosphorus (TP), Total Nitrogen (TN) and Ammonia (NH3), pertaining to different land use/ land cover categories. The values were given the shape of an export coefficient table (Table 3), which was used in the estimation of the pollutant loads.

Model Simulations: After running the PLOAD model, graphic and tabular output results were obtained for two simulation categories viz. annual pollutant loading by watershed area [Fig. 5(a-f); Table 4] and total annual pollutant loading by watershed [Fig. 6(a-f); Table 5]. PLOAD model, thus, simulated the pollutant loads coming from the watersheds in the catchment into the Hokersar wetland.

Discussion

During the present investigation, a total of 5 watersheds of the Hokersar wetland catchment were assessed in terms of pollution loadings coming from different land use/land covers. Amongst these watersheds number 1 and 5 witnessed the highest annual loads of all the pollutants except TSS. The reason for this may be attributed to the fact that these watersheds are under direct biotic interference. Also the maximum number of land use/land cover classes is present in these watersheds. Land use classes such as built up (urban), agriculture and aquatic vegetation contribute to the maximum of these pollutants such as total phosphorous, ammonia, nitrites and nitrates which ultimately find their way into Hokersar through agricultural runoff and domestic sewage, etc.

Table 3 - Export Coefficient in (lbs/ac/yr).

LUCODE	CLASS	BOD	TSS	TDS	NH3	Total Nitrogen	Total Phosphorus
1.	Plantation	59	124	424	4.7	31	6.4
2.	Meadow	21	143	493	3.6	25	5.1
3.	Scrub	18	425	151	2.5	19	5.0
4.	Bare rock	15	492	137	2.1	18	4.8
5.	Forest	33	162	521	3.9	22	5.6
6.	Snow	-	-	-	-	-	-
7.	Boulder	43	632	197	4.4	33	9.7
8.	Agriculture	52	136	587	4.4	34	9.5
9.	Built-up	132	505	201	6.1	30	12.6
10.	Aquatic vegetation	157	144	462	5.5	31	8.6
11.	Stream	106	673	219	5.0	34	10.1
12.	Karewas	32	388	174	2.7	19	4.8

Table 4 - Annual pollutant loading by watershed area in (lbs/ac/yr).

Watershed ID	BOD	TSS	TDS	NH3	TN	TP
1.	31.81	259.88	370.67	3.42	23.20	5.79
2.	45.18	247.49	373.62	3.72	26.85	6.91
3.	35.86	234.77	393.21	3.57	24.94	6.32
4.	55.80	163.15	486.56	4.39	31.53	8.12
5.	67.26	194.75	445.56	4.67	31.38	8.39

Excessive nutrients such as nitrates and phosphates, commonly originate in domestic sewage, runoff from agricultural fields, waste material from animal feed lots and packing plants etc. These nutrients are responsible for water pollution primarily because they stimulate the growth of microorganisms which often increase the biochemical oxygen demand (BOD). Highest BOD values were recoded for watershed number 5 and 1 with total annual loads of 2981550.40 lb/yr and 1580010.08 lb/yr respectively. BOD is an indicator and not a pollutant. Higher BOD values indicate strong sewage and hence it is used to measure the degree of water pollution and waste strength.

The highest load for total dissolved solids came from watershed number 5 and 1 with a total load of 19749786.56 lb/yr and 18411280.09 lb/yr respectively, whereas the highest load for total suspended solids was recorded in the watershed number 1 and 3 with values of 12908535.70 lb/yr and 9355625.74 lb/yr respectively. Doodhganga and Shaliganga streams bring in a lot of suspended solids (silt), which has been degrading the wetland for past few decades. Total solids of water are dependent upon the concentration of suspended and dissolved solids. Increase in the dissolved solids indicates increase in the concentration of the included elements and therefore eutrophication. Brehmer[14] observed the latter is caused as the result of decrease in compensation depth by increasing the concentration of suspended solids. Hem[15], Seddon[16] and Goel *et al.*[17] related deterioration of water quality to increase of total solids, and used total solids content of water as a criterion for confirming the eutrophic nature of water.

The annual loads of ammonia were highest in the watershed number 5 and 1 with values of 207241.92 lb/yr and 169693.51 lb/yr respectively. The higher values of ammonia may be attributed to the pres-

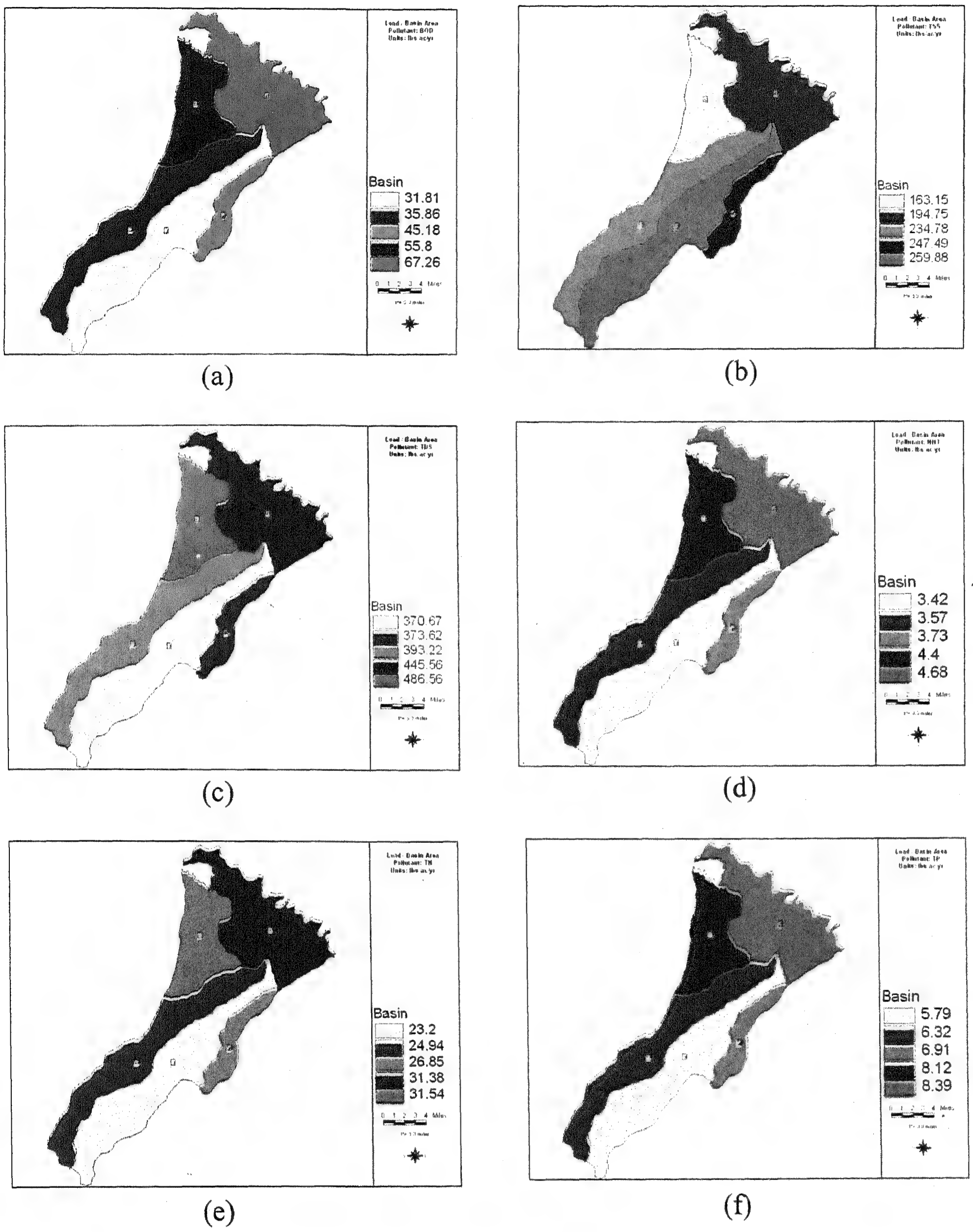


Fig. 5(a-f) - Maps showing annual pollutant loading of BOD, TSS, TDS, NH3, TN and TP respectively by watershed area

ence of organic pollution. Baumeister [18] reported that ammonia is a good indicator of sewage pollution. Srivastava and Sahai [19] reported very high free ammonia concentration in polluted area of the Chilwa lake.

Similarly the annual loads of total nitrogen and total phosphorous were also highest for the two watersheds 5 and 1, the values being 1391053.11 lb/yr and 1152527.21 lb/yr for nitrogen and 372044.15 lb/yr and 287427.19 lb/yr for phosphorus, respectively. Hutchinson [20] reports the higher levels of phosphorous are the results of sewage contamination. Thomas [21] pointed out that addition of phosphorous brings about in eutrophication mechanism by increasing the bacterial content, increase in the oxygen demand and increase in growth of algae. Hammer [22] reveals that as contrasted to most of other major ions the contribution of nitrogen and phosphorous to water is directly or indirectly at-

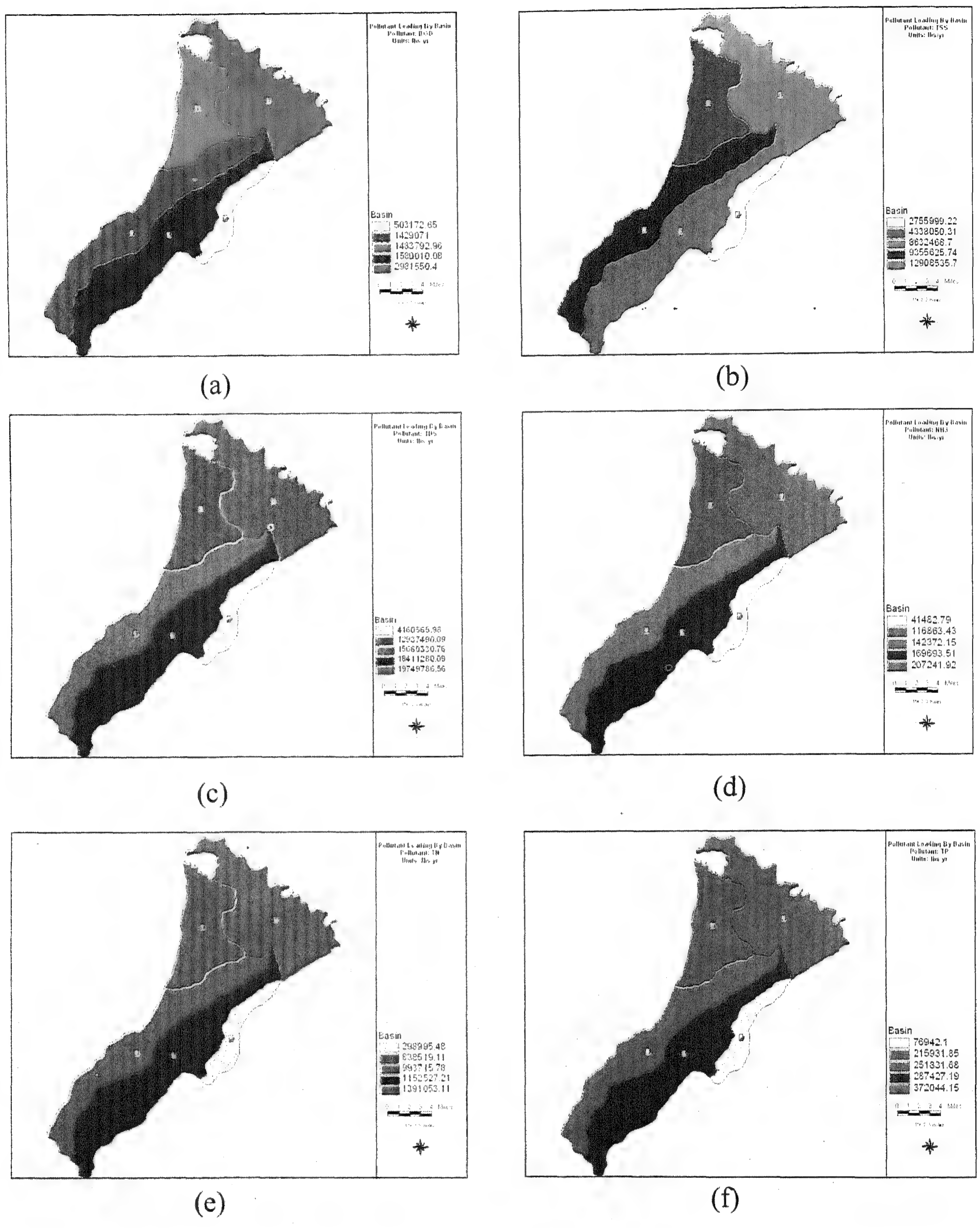


Fig. 6(a-f) - Maps showing annual pollutant loading of BOD, TSS, TDS, NH3, TN and TP respectively by watershed.

tributable to the activities of human beings. Edwards and Goodman [23] while outlining the main pollution problems of air, water and soil support the view of phosphorous and nitrogen being implicated in accelerating eutrophication process. Frecker and Davis[24] discussed the man made eutrophication in the Newfoundland Harbour (Canada) and found that phosphorous and nitrogen were the major culprits in accelerating the process. Similar findings have been reported by Prasad and Qyum [25].

Conclusion

Hokersar pollution provides a classic example of how little the beauty of nature can be appreciated. There has never been a time when man kind has not modified his environment, but the changes that are taking place now are major and rapid as compared to those of the past. Different watersheds have a maximum loading of different pollutants which is dependent upon different land use/land covers. The highest

Table 5 - Total annual pollutant loading by watershed in (lbs/year).

Watershed ID	BOD	TSS	TDS	NH_3	TN	TP
1.	1580010.08	12908535.70	18411280.09	169693.51	1152527.21	287427.19
2.	503172.65	2755999.22	4160565.98	41482.78	298995.48	76942.09
3.	1429071.00	9355625.74	15669330.76	142372.15	993715.77	251831.67
4.	1483792.96	4338050.31	12937490.09	116863.43	838519.11	215931.85
5.	2981550.40	8632468.70	19749786.56	207241.92	1391053.11	372044.15

loads were witnessed in watershed number 1 and 5 in the catchment in which built up (urban), agriculture, aquatic vegetation and stream were the dominant land use/land covers. The different pollutants coming from these watersheds are contributing towards the steady degradation of this beautiful wetland. As a result, the Hokersar wetland is facing an unsung death. It is concluded that the urban and Doodhganga watershed in Hokersar catchment assume top most priority and thus need to be effectively managed on pollutant basis. This research demonstrated the usefulness of remote sensing, GIS and simulation modeling for understanding the pollution loads in a wetland catchment area.

Acknowledgments

The authors are highly thankful to the Wildlife Warden (Wetlands), Department of Wildlife Protection, J and K State for granting permission to work inside Hokersar Wetland Reserve. Thanks are also due to the Head, P.G. Department of Geology and Geophysics, University of Kashmir for providing laboratory facilities.

References

1. Pandit AK. Biotic factor and food chain structure in some typical wetlands of Kashmir. PhD. Thesis. University of Kashmir, Srinagar, 1980.
2. Pandit AK. Conservation of wildlife resources in wetland ecosystems of Kashmir, India. *J Environ Manage* 1991; **33** : 143-154.
3. Pandit AK, Qadri SS. Floods threatening Kashmir wetlands. *J Environ Manage* 1991; **31** : 299-311.
4. Khan MA. Wetland biodiversity in the Kashmir Himalaya: Assessment and conservation strategies. In: Khan MA, editor. Environmental Biodiversity and Conservation. New Delhi: APH Publishing House, 2000. pp. 69-93.
5. Rather SA, Bhat SA, Pandit AK. Water quality of Hokersar, a typical wetland of Kashmir. *J Res and Dev* 2001; **1**: 38-43.
6. Lung WS. Assessing phosphorus control in the James River Basin. *J Environ Engineering* 1986; **112(1)** : 44-60.
7. Thomann RV, Mueller JA. Principles of Surface Water Quality Modeling and Control. New York: Harper and Row Publishers, 1987.pp 1-644.
8. Kuo JT, Wu JH. A nutrient model for a lake with time-variable volumes. *Wat Sci Tech* 1991; **24(6)** : 133-139.
9. Anonymus. User's manual Better Assessment Science Integrating Point and Non-point Sources (BASINS) version 3.0. Report No. **823-H.01.001**, US, USEPA, 2001.
10. Baldys S, Raines TH, Mansfield BL, Sandlin JT. Urban stormwater quality, event-mean concentrations, and estimates of stormwater pollutant loads, Dallas-Fort Worth area, Texas, 1992-93. *U.S. Geological Survey Water-Resources Investigation Report* 1998; 98 : p. 4158.
11. Mcfarland AMS, Hauck LM. Determining nutrient coefficients and source loading uncertainty using in stream monitoring data. *J Amer Water Res Ass* 2001; **37(1)** : 223-236.
12. Line DE, White NM, Osmond DL, Jennings GD, Mojonnier CB. Pollutant export from various land uses in the Upper Neuse River Basin. *Water Env Res* 2002; **74(1)** : 100-108.
13. Badar B, Romshoo SA. Modeling the non-point source pollution load in an urban watershed using remote sensing and GIS: A case study of Dal lake. *J Himalayan Ecol and Sust Dev* 2007; **2** : 21-32.
14. Brehmer ML. Turbidity and siltation as forms of pollution. J *Soil and Water Conservation* 1965; **20(4)** : 132-133.
15. Hem JD. Study of interpretation of the chemical characteristics of natural water. Second edition, *US Geol Sur Water Supply Paper* 1473. 1970. pp 1-363.
16. Seddon B. Aquatic macrophytes as limnological indicators. *Freshwat Biol* 1972; **2** : 107-130.
17. Goel PK, Gopal B, Trivedi RK. Impact of sewage on freshwater ecosystem II. Physico-chemical characteristics

of water and their seasonal changes. *Int J Ecol Environ Sci* 1980; **6** : 97-116.

18. Baumeister R. Chemical analysis of selected public drinking water supplies (including trace metals). Tech Bull No. 53. Wisconsin: Dep Nat Res Med, 1972.

19. Srivastava VC, Sahai R. Effects of water pollution on periodicity and productivity of phytoplankton of Chilwa lake. *Geobιos* 1976; **3(6)** : 187-189.

20. Hutchinson GE. A treatise on limnology. Vol.1. New York: Wiley, 1957.

21. Thomas EA. The process of eutrophication in central European lakes. Eutrophication: causes, consequences, correctives. *Nat Acad Scι Washington* DC 1969; 29-49.

22. Hammer UT. Limnological studies of the lakes and streams of upper Qu Appelle River System, S'arkalchewan, Canada, I. Chemical and physical aspects of lakes and drainage system. *Hydrobiologia* 1971; **37(3-4)** : 473-507.

23. Edwards RW, Goodman IG. Pollution of air, soil, freshwater and the sea. *Intern J Environ Studies* 1972; **2** : 263-269.

24. Frecker MF, Davis CC. Man made eutrophication in a Newfoundland (Canada) Harbour. *Int Rev Hydrobiol* 1975; **60(3)** : 379-393.

25. Prasad DY, Qyum MA. Pollution aspects of upper lakes of Bhopal. *Ind J Zool* 1976; **4(1)** : 35-46.

Proc. Nat. Acad. Sci. India, Sect. B, Vol. 78, Spl. Issue, 2008

Net primary production, turnover and system transfer functions in floating grasslands of Keibul Lamjao National Park (KLNP), Manipur, N.E. India.

DAISY ANGOM and ASHA GUPTA*

Ecology Research laboratory, Deptt. of Life Sciences, Manipur University, Canchipur, Imphal-795003, India.

**e-mail: anjalika_22000@yahoo.co.in*

Abstract

Keibul Lamjao National Park (KLNP) is a unique floating park in Manipur. The changes in hydrological regime of Loktak lake (A Ramsar Site) has affected the *vast floating mat* at Keibul Lamjao National Park - (KLNP (Latitude 23° 83' N to 25° 86' N; Longitude 93° 03' E - 93°78' E) at Manipur, N.E. India which has ceased to experience its annual draw-down cycle since the construction of Ithai barrage in 1984. KLNP, the only natural abode of famous and endangered brow-antlered-deer, *Cervus eldi eldi*, Mc Cleland supports unique floating grasslands over a heterogenous mass of organic matter locally called as phumdis. The present study is undertaken to evaluate the primary productivity and dry matter dynamics of grasslands of KLNP. The seasonal and annual drymatter production and its transfer through different producer compartments viz. live shoot, dead shoot, litter and root were analysed. Net accumulation rates, disappearance rates and turnover were calculated.

Key words : Keibul Lamjao National Park, draw down cycle, floating mat, dry matter production, system transfer function

सारांश

कैबुल लमजाओ नेशनल पार्क (के एल.एन पी.) मणिपुर का एकमात्र प्लावी पार्क है। लोकटक झील (जो एक रामसार स्थल है) मे होने वाले जलविज्ञान संबंधी परिवर्तनों ने, मणिपुर, उ पू भारत के कैबुल लमजाओ नेशनल पार्क (23°83' उ. से 25°86' उ. अक्षांश, 93°03 पू से 93°78' पू देशांतर) के असीम प्लावी–परत को प्रभावित किया है, जिसमे 1984 मे बने इथाई बॉध के कारण वार्षिक जल के आने–जाने का चक्र लगभग समाप्त सा हो गया है। केबुल लमजाओ नेशनल पार्क, जो प्रसिद्ध तथा विलुप्तप्राय ब्रो ऐन्टलर्ड हिरन, *सरवस एल्डी एल्डी* मेक क्लीलेंड का प्राकृतिक निवास है, अपने कार्बनिक पदार्थ की विषमजातीय मात्रा में जिसे स्थानीय भाषा में फुमदिस कहते है, एक मात्र प्लावी घास के मैदानो को समेटे हुये है। प्रस्तुत अध्ययन में के.एल एन पी के घास के मैदानो की प्राथमिक उत्पादन क्षमता तथा शुष्क पदार्थ गतिकी का मूल्याकन किया गया है। विभिन्न मौसमों मे तथा वार्षिक रूप मे शुष्क पदार्थ का उत्पादन और विभिन्न उत्पादन कोष्टको, जैसे जीवित अकुर, मृत अकुर, जनित और जड के बीच इनके स्थानान्तरण का विश्लेपण किया गया है। नियत संचय दर, लोपदर तथा घूर्णन का परिकलन किया गया है।

सांकेतिक शब्द : कैबुल लमजाओ नेशनल पार्क, ड्रा–डाउन चक्र, प्लावक घास की चटाई, शुष्क पदार्थ उत्पादन, तत्र स्थानान्तरण कार्यकी।

Introduction

Primary productivity forms the basis of all dynamic functions of the living world. Total dry matter production is considered to be a measure of its system efficiency to fix energy in all its compartments[1]. Thus, the net primary production is the rate of storage of organic matter in plant tissue in excess of respiratory utilization by plants during the experimental period and is the main source of energy for other trophic levels in an ecosystem[2]. Hence it is an essential step in understanding the functioning of an ecosystem[3].

In production analysis four major compartments viz. aboveground (live shoot), standing dead, litter and below ground (roots) are distinguished, The inter compartmental interactions reflect the functioning of the system in time and space. The rate of production of organic matter is controlled by the rate of input of radiant energy and its fixation in photosynthesis. True gross photosynthesis is the rate of transformation of radiant energy to chemical energy which, of course, is accompanied by equivalent conversions of CO_2 and H_2O into carbohydrate and oxygen. Respiration consumes oxygen and converts some of this organic matter back to CO_2 and H_2O. When nutrients are not limiting, the rates of net photosynthesis and increase in biomass are often high as photosynthesis per unit surface area increases with biomass[4].

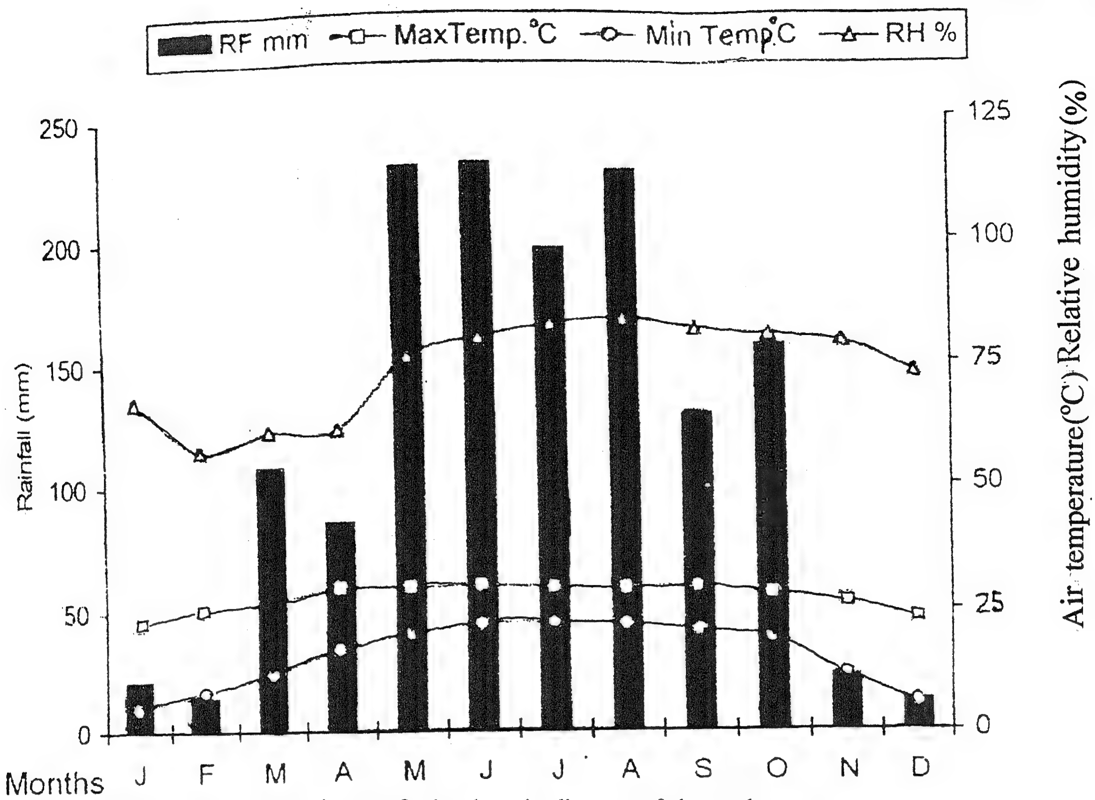


Fig. 1 - Ombrothermic diagram of the study area.

Bioresources are found to be very much degraded in the north-eastern India which is also one of the 25 "Biodiversity Hotspots" of the world[5]. Moreover, very little information is available on the productivity studies of grasslands in north-eastern India except a few[6,7,8,9]. Till now no work on productivity studies on KLNP has been reported. The present paper attempts to study the following:—

* Shoot net primary productivity
* Root net primary productivity
* Total net primary productivity
* Turnover rates
* Dry matter dynamics in different primary producer compartments and disappearance rates and
* System transfer functions

Study Area

Manipur, lies in the north north-eastern part of India. The Tropic of Cancer passes through the state and extends between 23°8' N to 25°68' N latitude and between 93°2' E to 94°78' longitude. The sub-tropical monsoonic type of climate with moderate temperature, rainfall and relative humidity prevails in the state. Fig.l. shows the ombrothermic diagram for the study site.

Keibul Lamjao National Park located under Bishnupur district of Manipur is the only natural habitat of Brow antlered deer, Sangai. It is situated at about 47 km from Imphal city and lies between 24°27' to 24°31' N latitude and 93°53' to 93°55' E longitude. The park is situated in the south-eastern side of Loktak lake and covers an area of about 40 sq. km (Fig.2).

The park is comprised of open waters, hillocks (Toya, Pabot, and Chingjao) and vast expanse of phumdis or floating mat supporting luxuriant grasses.

About two-third of the park is covered by Phumdi (a heterogeneous mass of soil, vegetation and organic matter in different stages of decay) which floats on water. Earlier the park experienced annual draw-down cycle. Thus the phumdi floated when the level of the lake rose and settled at the bottom when the level of the water dropped during the dry periods. However, after the construction of Ithai barrage in 1984 the annual cycle ceased and the phumdis remain floating throughout the year.

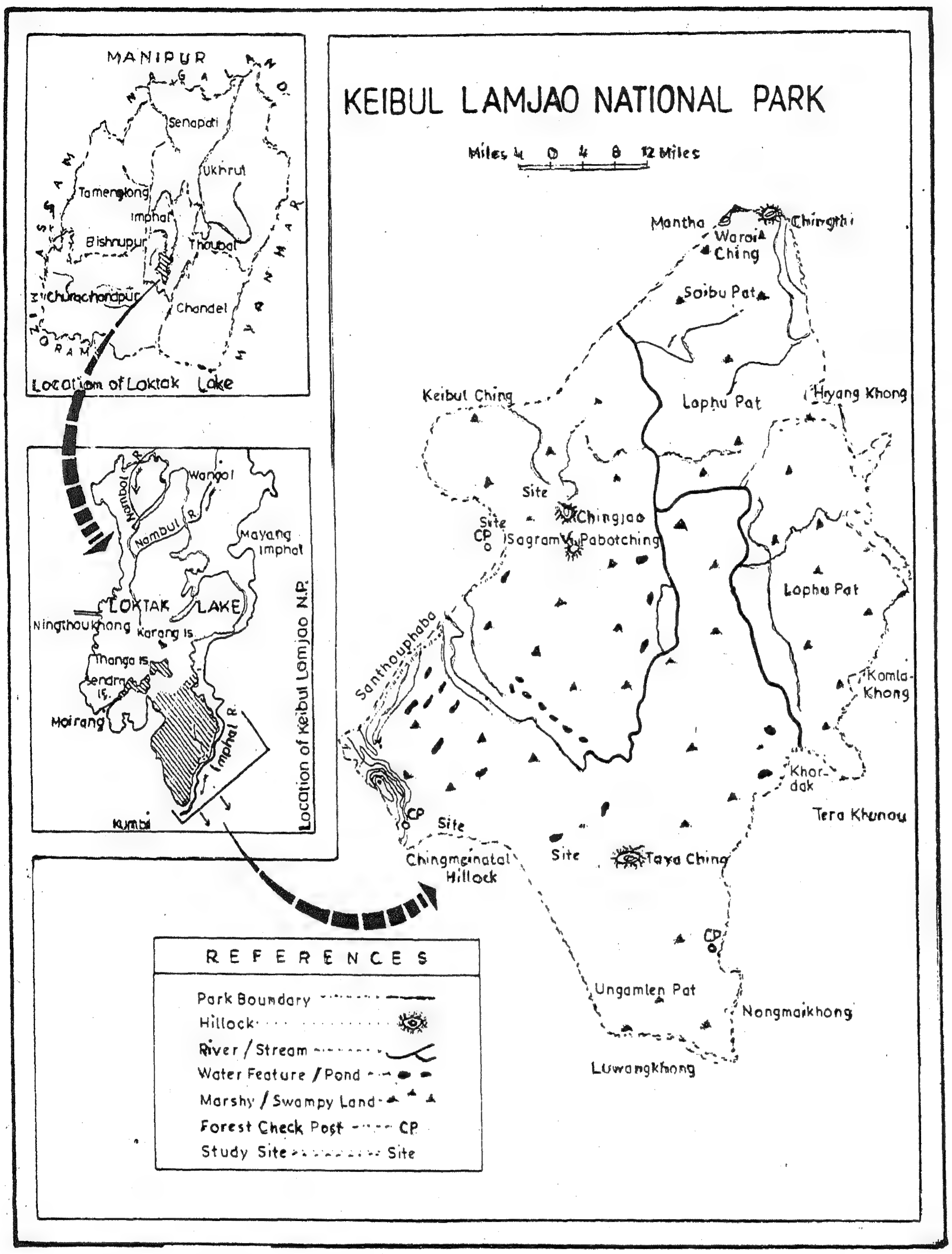


Fig. 2 - Map of the study area (Keibul Lamjao National Park) showing location.

Phumdi varies in thickness from a few centimeters to two meters. The humus of phumdi is of black colour and very spongy with large number of pores. About 20% of phumdi remains above water.

Phumdis are nutrient efficient, containing 1.2%-1.5% of Nitrogen, 0.045%-0.129% of Phosphorous and 1.09%-1.31% of Potassium. A clear water zone exists under the phumdis whose depth varies with the fluctuation of water level. The water below phumdi is acidic. Nutrient concentration is low except for Sodium. The average annual values of some of the nutrients are : N = 0.085mgl^{-1}, P = 0.0005mgl^{-1}, K = 2.35 mgl^{-1}, Ca = 7.77 mgl^{-1}, Na = 12.43 mgl^{-1}. Under water there is a nutrient rich sediment[10].

The phumdis provide food and shelter to Sangai, and also are the chief sources of vegetables, fodder, fuel, cultural activities and even medicine for the people. However, it has been found that most of the plant

collected by human beings are also the preferred food plants of Sangai which creates competition between human beings and the deer. The overlapping of such utilization pattern of the park resources has resulted in declining population of these plants[11].

Another unique offer made by the phumdi to Sangai is that it can readily bear its weight. The deer thus moves on the phumdi in a characteristic style with the hind limbs bearing the body weight, the forelimbs raised high and the animal takes a small hop, maintaining the balance, not sinking in the phumdi. Because of this style of locomotion Sangai is also called the dancing deer[12].

The dominant species from the floating park includes *Oplismenus compositus, Sacciolepsis myosuroides, Zizania latifolia, Hedychium coronarium etc.for* the present investigation, four sites have been selected from the park: viz site I (Toya outer), site II (Toya inner), site III (Pabot outer) and site IV (Pabot inner). All the four sites are important grazing and resting spots of the deer.

Material and Methods

For the present investigation, Harvest method was employed. The Net Primary productivity was calculated[13] and the net accumulation and disappearance rates were estimated[14,15,16]. Turnover rates of shoot and root components were also studied.

Results and Discussion

Table I reflects the annual net primary production and its seasonal trends for 4 sites of KLNP. Figs 3(a) to 3(d) reflect the dry matter dynamics. The values along arrows indicate accumulation and disappearance rates in $gm^{-2}\ d^{-1}$ and table 2 shows the system transfer functions in different seasons for 4 sites of KLNP.

Shoot Net Production (SNP)

Total annual SNP was minimum at site I. The recorded value was $1668 mg^{-2} yr^{-1}$ with a daily net production rate of $4.56\ gm^{-2} day^{-1}$. Site II recorded maximum SNP as $2259\ gm^{-2} yr^{-1}$ with $5.17\ gm^{-2} day^{-1}$ as daily production rate. At site II, the highest production was recorded in winter season where as the minimum was recorded in summer season. Site II and III showed the production pattern as rainy>winter>summer. However, the seasonal range at site III varied from $356\ gm^{-2}$ in winter to $890\ gm^{-2}$ in rainy season with total annual net production as $2167\ gm^{-2} yr^{-1}$ and daily net production rate as $4.56\ gm^{-2} day^{-1}$ (Table 1). Site IV recorded a range in seasonal production as $191\ gm^{-2}$ in summer to $820\ gm^{-2}$ in winter with total annual production value as $1721\ gm^{-2}$ and a daily net o production rate as $4.71\ gm^{-2}\ day^{-1}$.

The highest production in site I in winter could be attributed to active growth of plants during winter accumulating maximum value of biomass. The highest production in rainy season in site II and III may be mainly because of higher soil moisture available to a relatively large number of species.

The highest productivity in summer (site IV) could be attributed to the initiation of sprouting and emergency of new growth in summer season.

The production pattern rainy>summer>winter recorded by the author at site II and III has also been observed by some other workers in Indian grasslands[17,18,19].

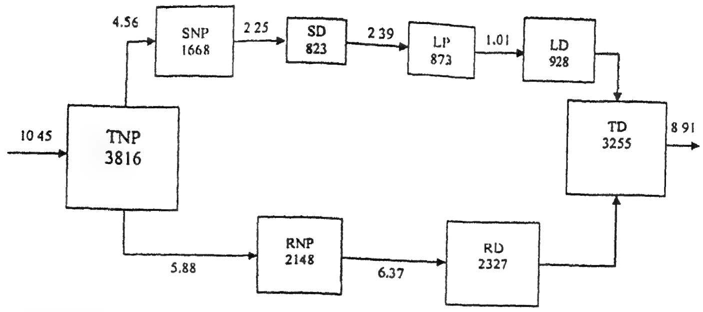
The varied shoot net production recorded at different sites is due to variations in photosynthesis rates of various species at different sites. Even various varieties and races within the same species demonstrate different photosynthetic rates.

The growth rate of plant expressed as the rate of increase in dry weight per unit area is termed as Net Assimilation Rate (NAR). Because of dependence of NAR on Leaf Area Index (LAI), the rate of dry matter production per unit area is equal to NAR x LAI. The productivity of species differs when measured under optimal condition of growth.

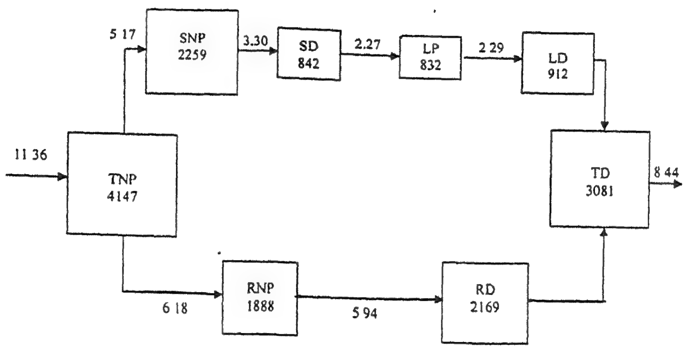
The shoot net production values found in the present study are lesser than the values recorded by some other workers[20,21,22,23,24,25,26] on one hand while more than the values recorded by others[34,36]. These values also are in agreement with the values of some workers[27].

The variation in values of productivity at 4 sites which are subjected to more or less same climatic conditions could be attributed to the impact or differences in soil physico-chemical characteristics as well as variations in species composition of vegetation among the four sites[14].

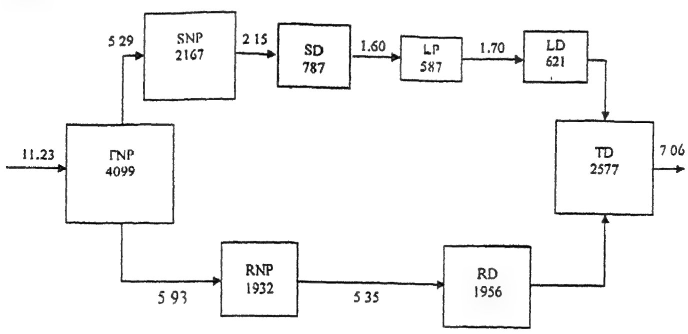
Site I : Fig.3a.



Site II : Fig: 3b



Site III : Fig: 3c.



Site IV: Fig 3d

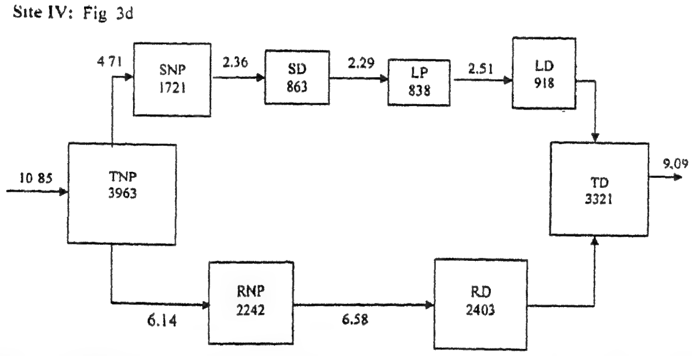


Fig. 3a. to 3d. - Dry matter dynamics in floating grasslands of KLNP, Manipur. Values along arrows indicate accumulation and disappearance rates (gm^{-2} day^{-1}) during the study period through the different compartments.

SNP = Shoot Net Production. SD = Shoot Disappearance. LP = Litter Production. LD = Litter Disappearance. RNP = Root Net Production. RD = Root Disappearance. TD = Total Disappearance.

Shoot Biomass Turnover

The seasonal turnover of shoot biomass was found highest in summer season for site I (0.310) and site II (0.846). The values ranged from 0.256-0.310 at site I and 0.051-0.846 at site II. Table 1 shows the shoot Biomass Turnover of the studied sites.

The recording of maximum turnover value in summer and minimum in winter was also reported by some earlier workers[12] which indicates that rate of replacement of shoot biomass was maximum in winter season. However, sites III and IV recorded a varied pattern giving maximum turnover value in winter thus showing that maximum replacement of shoot has occurred in winter which may be attributed to vigorous growth of species. The maximum turnover rate recorded in winter for sites III and IV were 0.376 and 0.386 respectively.

The annual replacement of shoot biomass at 4 sites varied between 0.723 at site I to 0.874 at site II. Thus, the system retains 13%-28% which may be attributed to shoot biomass, shoot net production and decomposition. The total replacement for shoot takes 1.14 to 1.38 yrs. The varied turnover rates of shoot biomass at four sites is indicative of the rapid rate of turnover of shoot biomass as majority of species are annuals. Annuals are also made accountable for rapid rate of turnover of shoot biomass[22]. The variation in turnover rates at four sites could be because of the variation in photosynthesis which plays a major role in determining the vegetation composition and also the turnover rate[28].

Turnover values less than 1.0 were also recorded by many ecologists[27,30,31,24,28]. The turnover for shoot biomass ranged between 1.14 years at site II to 1.38 years at site I. The annual turnover and turnover time observed varies from 0.54 at Jhansi[22] to 2.15 at Canchipur, Manipur[25] in the Indian grasslands thereby indicating that the turnover time of these grasslands varied from 5.6 to 22.2 months. It is thus evident that the annual turnover and turnover time observed in the present study is found to be in agreement with those reported by some of the workers in different Indian grasslands.

Root Net Production (RNP)

Highest RNP at all the four sites of KLNP ranged between 1888 $gm^{-2}yr^{-1}$ at site II to 2242 $gm^{-2}yr^{-1}$ at site IV. In KLNP, the highest daily production rate was found in summer and least in winter. The recording of least root net production in winter may be due to maximum upward translocation of material to provide nourishment to new tillers.

The high production in summer is also in agreement with the findings of some other workers.[32,22] The highest root net production recorded in summer may be due to downward translocation of photosynthetic material leading to root growth[33].

Root Biomass Turnover

The maximum root biomass turnover rate was recorded in winter season for sites I and IV (0.590 each). At sites II and III the rate of biomass turnover in rainy season was from 0.440 to 0.540 respectively.

Rapid turnover of root biomass in winter indicates the nature of grassland which is an assemblage of a majority of annuals. The low turnover values in summer season (sites I and IV) and winter season (sites II and III) may be due lower rates of replacement of roots of perennial species. The turnover time for root biomass varied between 1.01 years at site IV to 1.30 years at site I. The turnover time required for the complete replacement of roots in Indian grasslands varied from 0.34 yrs at Jhansi[22] to 5.55 yrs at Garhwal Himalaya[29]. It is evident that the annual turnover and turnover time found in the present study agrees with those reported by other workers in different grasslands of India.

Total Net Production (TNP)

Yearly TNP varies between 4147 $gm^{-2}yr^{-1}$ at site I to 3816 $gm^{-2}yr^{-1}$ at site IV. The seasonal trends vary at the 4 sites being highest in summer at sites III, in rainy season and at site I and in winter season at site II and IV (Table I). Thus differences in the production of 4 sites in KLNP with similar climatic conditions could be attributed to differences in species composition, physiographic conditions and soil moisture storage.[19, 24]

The total net production values of the study sites are, on one hand comparable with the values recorded by some other workers,[27, 34] while on the other hand they are higher than such values.[32,21,22,17,35,26,518].

The turnover time for total biomass varied between 1.78 years at site III to 8.54 years at site IV in winter season, 2.01 years at site IV to 4.04 years

Table 1 - Seasonal and annual net primary production for 4 sites of KLNP.

Seasons	SNP				Shoot turnover				RNP				Root turnover				TNP			
	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV
Winter	490	1228	356	820	0.256	0.051	0.376	0.386	156	589	381	1139	0.590	0.269	0.277	0.590	648	1817	737	1959
Summer	513	110	686	191	0.310	0.846	0.273	0.127	1019	970	1185	149	0.106	0.320	0.350	0.106	1532	1080	1871	340
Rainy	705	550	890	710	0.290	0.370	0.290	0.250	971	700	601	954	0.350	0.440	0.540	0.420	1676	1250	1491	1664
Annual	1668	2259	2167	1721	0.723	.0874	0.775	0.781	2148	1888	1932	2242	0.767	0.860	0.820	0.987	3816	4147	4099	3963

Table 2 - System Transfer functions in different seasons for 4 sites of KLNP.

Compartments	Site I				Site II				Site III				Site IV			
	W	S	R	Annual	W	S	R	Annual	W	S	R	Annual	W	S	R	Annual
TNP to SNP	0.74	0.33	0.42	0.43	0.67	0.10	0.44	0.45	0.48	0.36	0.59	0.47	0.56	0.42	0.42	0.43
TNP to RNP	0.26	0.66	0.58	0.56	0.32	0.90	0.56	0.54	0.51	0.63	0.40	0.53	0.44	0.58	0.57	0.56
SNP to SD	0.30	0.56	0.49	0.49	0.20	0.34	0.38	0.44	0.83	0.44	0.44	0.40	0.253	0.16	0.40	0.50
SNP to Litter	0.10	0.70	0.65	0.52	0.02	4.5	0.57	0.44	0.51	0.26	0.25	0.30	1.01	0.22	0.64	0.49
SD to Litter	0.33	1.23	1.31	1.06	0.09	1.32	1.47	0.98	0.61	0.59	0.56	0.74	0.39	1.36	1.57	0.97
Litter to LD	0.2	1.07	1.05	1.06	1.00	0.91	1.29	1.09	0.72	1.26	1.01	1.05	0.47	1.31	1.08	1.09
RNP to RD	4.42	0.44	1.21	1.08	0.50	0.58	1.85	0.96	3.64	0.16	0.60	0.90	2.40	0.29	1.63	1.07
TNP to TD	1.16	0.54	0.99	0.85	0.17	0.94	1.36	0.74	2.06	0.22	0.39	0.62	1.32	0.29	1.22	0.83

Codes : TNP = Total net primary production. SNP = Shoot net primary production

RNP = Root net primary production. SD = Standing dead, LD = Litter disappearance

RD = Root disappearance, TD = Total disappearance.

at site II in summer season and 2.89 years at site IV to 3.64 years at site II in rainy season.

The maximum daily TNP at site II was 11.36 gm^{-2} day^{-1} whereas the minimum TNP found at site I was 10.45 $gm^{-2}day^{-1}$.

The RNP rate ranges from 5.88 $gm^{-2}day^{-1}$ at site I to 6.18 gm^{-2} day^{-1} at site II. The SNP rate ranges from 4.56 $gm^{-2}day^{1}$ at site I to 5.29 $gm^{-2}day^{-1}$ at site III. {Fig 3 (a) to 3(d)}. At all the sites the RNP rate was higher than SNP rate.

SNP rate varied from 1.55 $gm^{-2}day$-^{1} at site IV to 9.98 $gm^{-2}day^{-1}$ at site II. It was higher in winter season at sites I, II and IV, whereas, site III, exhibited higher rate of SNP as 7.29 gm^{-2} day^{-1} in rainy season. It may be due to excessive available moisture and congenial temperature helping in vigorous growth of vegetation. Similarly, higher RNP rate during the winter and summer months may be due to transfer of excessive photosynthates to the root system to be used for the next year's growth and partly due to less decomposition by soil microfauna in drier and cold conditions. Greater rates of production of above ground (live) shoot biomass during the rainy season was observed by some workers.[36,2] The rate of production for grasslands at Kurushetra was found to be 15.1$gm^{-2}day^{-1}$ during rainy season and 9.7 $gm^{-2}day^{-1}$ for the whole year.[35] Transfer from SNP to SDP was maximum at site IV (2.36 $gm^{-2}day^{-1}$) and minimum at site III (2.15gm^{-2} day^{-1}).

Table II reveals the system transfer functions for the four sites of KLNP. The rate of SNP to SDP was highest in rainy season for sites I and III (2.85 gm^{-2} day^{-1} and 3.203 gm^{-2} day^{-1} respectively). However site II exhibited maximum rate of transfer of SNP to SDP during summer season (3.125 gm^{-2} day^{-1} and during the winter season at site IV 3.94 gm^{-2} day^{-1}. Highest rate of transfer during winter season was attributed to the fact that during the winter season, there is death of annuals. Due to low temperature of atmosphere and soil and less available water the plants undergo a period of stress (drought) which results in the death of certain plant parts. Further due to the advanced growth period especially of grasses, the plant enters the senscene phase which results in the production of more standing dead material[37]. The transfer of above ground (live) shoot biomass to standing dead compartment was found to be more during winter season in Kurukshetra grasslands[23].

Litter production rate of Transfer of standing dead to litter compartments was found highest at site I as 2.31 gm^{-2} day^{-1} and minimum at site III as 1.60 gm^{-2} day^{-1} on annual basis.

However, for sites I, III and IV, the transfer rate of SDP to Litter compartments was found maximum during rainy season varying between 1.84 gm^{-2} day^{-1} at site III to 3.75 gm^{-2} day^{-1} at site I and IV, whereas, site II exhibited maximum transfer rate of standing dead to litter seen during summer season as 4.12 gm^{-2} day^{-1}. It may be due to more drying up of standing dead plant material and its further breaking due to wind or rain action. Litter disappearance rate was found maximum at site IV as 2.51 gm^{-2} day^{-1} and minimum at site I as 1.01 gm^{-2} day^{-1} on annual basis.

Litter disappearance (LD) was found maximum as 3.76 gm^{-2} day^{-1} during summer season for sites II and III. More litter disappearance during summer months can be due to enhanced microbial activity due to congenial temperature and moisture conditions of the soil. However, LD rate was found maximum for sites I and IV during rainy season which has also been reported earlier.[37]

Highest root disappearance rate (RD) found at site IV was 6.58 gm^{-2} day^{-1} whereas lowest RD rate was 5.35 gm^{-2} day^{-1} at site III. Seasonally, maximum Root disappearance (RD) was found in rainy season at sites I, II, IV as 9.65 gm^{-2} day^{-1}, 10.65 gm^{-2} day^{-1} and 12.66 gm^{-2} day^{-1} respectively. Maximum RD was noted for site III during winter season. Higher root disappearance rate during the rainy season is due to more death and decay of previous years roots and low root formation in the early growing season. Further, the higher decay rates in winter can be due to the excessive consumption of roots by soil macro and micro organisms.

Annual highest total disappearance (TD) rate found at site IV was 9.01 gm^{-2} day^{-1} and lowest TD rate was recorded from site III as 7.06 gm^{-2} day^{-1}. On seasonal basis maximum TD rate was recorded in rainy season for sites I, II and IV as 13.63 gm^{-2} day^{-1}, 13.9 gm^{-2} day^{-1} and 16.75 gm^{-2} day^{-1} respectively. However at site III, the maximum TD rate recorded in winter season was 12.37 gm^{-2} day^{-1}. The minimum rate of TD recorded in winter season for sites I, II and IV was 5.75 gm^{-2} day^{-1}, 2.63 gm^{-2} day^{-1}, 3.65 gm^{-2} day^{-1} respectively. At site III, the minimum rate of TD recorded in summer season was 3.57 gm^{-2} day^{-1}. Maximum values

of TD during summer season were also observed by some workers[37].

System Transfer Functions were calculated on the basis of annual production and their transfer in different components. System Transfer Function is the quantity by which the system block multiplies the input to generate the output. The values of these functions have been calculated for winter, summer and rainy seasons and also on annual basis using the values in block diagrams. The values on annual basis indicate a transfer of 43% at sites I and IV to 47% at sites II and III of TNP to SNP and 53% at site III to 56% at site I of TNP to RNP. ANP and BNP accumulation is 32% and 68% respectively of TNP in Kurukshetra grasslands[23]. Annual accumulation of dry matter in below ground biomass ranges from 46% to 64% of TNP, 36% to 54% in above ground biomass and 25%-33% in below ground biomass during 1973-74 near Pilani.[38]

The maximum transfer from TNP to SNP was seen during winter season. It ranged between 48% at site III to 74% at site I. However, site III recorded maximum transfer of 59% during rainy season. The transfer of TNP to RNP was maximum during summer for all the sites ranging between 58% at site IV to 90% at site II. The transfer of SNP to SDP on annual basis was found highest as 50% at site IV and a minimum of 40% at site III. Transfer for SNP to SDP was 56% at site I and 34% at site II during summer season. However, sites III and IV recorded maximum transfer of SNP to SDP as 40% and 50% respectively during winter season. The annual SDP was found to vary between 787 gm^{-2} to 863 gm^{-2}. The transfer for ANP during 2 years of study by Bawa[37] found maximum during the winter season during the first year, where it was highest of 382% during summer season in the 1st year and 647% during winter season during the second year. Thus it suggests a higher transfer of rainy season annuals and also leafy parts of perennials through rapid maturity of tillers during the winter season. High transfer rates of 547% in winter season have been reported[9]. A maximum transfer rate range of 1029%-1982% on the five sand and dune sites near Pilani have also been reported during 2 years of study.[37]

Transfer from Shoot net production (SNP) to Litter production (LP) ranged between 30% at site III to 52% at site I on annual basis. Sites I and II recorded maximum transfer during summer season as 70% and 45% respectively. Sites III and IV recorded maximum transfer from SNP to litter production during winter season as 51% and 101% respectively. Transfer to litter from above ground biomass was more than 95% in grazing lands of Garhwal, Himalaya.[24]

Transfer rate to SDP to litter compartments varied between 74% at site III to 106% at site I in KLNP. The maximum transfer to litter was found during rainy season at sites I, II and IV. It varied between 131% to 157%. However, site III showed maximum transfer from SDP to litter as 61% during winter season. Thus on annual basis the transfer rate was 84%-100%[37]. Higher transfer rates for one of the sites during rainy season was 428% and for another site as 100% during winter season. 18% to 109% of SDP found its way to litter compartment within a year[38]. 75.60% of SDP (84.50% if higher estimates are considered) makes its way to litter production.[23]

Litter disappearance varied between 105% at site III to 109% at site II and IV. On seasonal basis, during summer, loss of litter was recorded at sites I, II and IV of KLNP. It ranged between 107% at site I to 131% at site IV. However, maximum loss of litter took place during rainy season at site II. 166%-560% loss of litter was recorded by some workers during summer season and between 139% to 284% for other sites during rainy season. However on annual basis LD values ranged from 93% to 112% at all sites during two years study period.[2] For Kurukshetra grasslands LD was recorded 93%[23]. 99% of litter found its way to litter disappearance at Harhar near Pilani.[37]

90%-108% of Root net production (RNP) at site III and site I respectively, was directed to root disappearance. The maximum transfer occured during winter season for sites I, III and IV as 442%, 364% and 240% respectively. However, site II recorded maximum root loss of 185% during rainy season. It suggests active root growth within a single year. On annual basis where the maximum root disappearance ranged between 73% to 196%, the seasonal values for rainy season ranged between 237% to 296% and for winter season as 462% for the study sites[38]. BNP disappearance of 80% has been reported for Kurukshetra grasslands[23] while 75% to 92% in five sand and dune sites around Pilani, Rajasthan[37].

The transfer value to total disappearance including litter and root disappearance indicated for KLNP sites ranged between 62% at site III to 85% at site I on annual basis.

On seasonal basis for 3 sites (I, II and III) higher system transfer value to total disappearance was recorded during winter season as 116%-200%. For site II, maximum transfer TD was obtained during rainy season as 136%. Thus, the study reveals that the accumulation of organic matter in the floating Phumdis of KLNP points out lesser microbial activities in the grasslands of the park.

Conclusion

The system transfer functions of KLNP indicate that most of the dry matter is channelised to roots and rhizomes indicating stressed condition in the park. It is also supported by the biological spectrum of KLNP[10] indicating dominance of chamaephytes and hemicryptophytes in the vegetation, Thus the dominance of species of longer and vigorous rhizomes indicates that under various biotic stresses the plants draw energy from root systems and rhizomes.

Earlier works[39], indicate the formation of close clusters of chamaephytes, hemicryptophytes and geophytes forming the dominant vegetation in the park reflecting the best performance of species belonging to geophytes, hemicrytophytes and chamaephytes, the interior sites facing grazing pressure from ungulates and burning stress is shown by majority of hemicryptophytes and chamaephytes where the food storage organs and buds for making fresh growth are adequately protected. It indicates higher accumulation of organic matter in the roots and rhizomes and shows stress conditions in the park.

The inner sites were found more species rich and diverse than the outer sites, the sites which are inner are also more productive. The inner sites reflect the influence of diverse set of factors like grazing and burning and hence permit a greater diversity of specialized species.

The dry matter which is available to the ungulates in the park comprises of 43%-47% from the shoot net production. As 105%-109% of litter disappears from the system it indicates that more dry matter disappeared annually. It also indicates that maximum dry matter is not available to ungulates as fodder which shows stress conditions in the floating park of KLNP. However higher net production rates ranging between 10.45 gm^{-2} day^{-1} to 11.36 gm^{-2} day^{-1} and disappearance rates varying between 7.06 gm^{-2} day^{-1} to 9.09 gm^{-2} day^{-1} indicate higher accumulation of organic matter in the floating grasslands of KLNP. Variations in the values of productivity at four sites which are subjected to more or less same climatic conditions could be attributed to impact or difference in physico-chemical characteristics of floating mat as well as variations in species composition of vegetation among the four sites.

References

1. Rochow JJ. Estimation of above ground biomass and primary productivity in a Missouri. forest *J Ecol* 1974; **62** : 567-577.
2. Odum EP. Fundamentals of Ecology. Philadelphia: Saunders WB. 1971.
3. Lauenroth WK, Whitman WC. Dynamics of dry matter production in a mixed grass prairie in West Northern Dakota. *Oecologia* 1977; **27** : 337-351.
4. UNESCO, UNEP. Natural Resource Research and gross and Net Primary productivity growth parameters. Paris-France: Natural Resource Research XV. 1978.
5. Myers N. Mittermeleer RA, Cristina CG, Mittermeler GAB, da fonseca, Kent J. Biodiversity hotspots for conservation priorities, *Nature* 2000; **24** : 853-858.
6. Ramakrishnan PS, Ram SC. Vegetation, biomass and productivity of several grasslands of Cherrapunji in N.E. India. *Vegetatio* 1988; **74** : 47-53.
7. Kakati LN, Yadava PS. Seasonal changes in chlorophyll and carotenoids contents in a grassland ecosystem at Imphal *Trop Ecol* 1990; **31** : 82-88.
8. Sharma BM. Wetland Ecosystem of Manipur; An ecological appraisal. In: Singh RKR, Sharma HP, editors. Wetland of Manipur Vol. (I) Imphal: Manipur Asia Science and Society (MASS), 1999.
9. Devi AR, Sharma BM, Sharma HM. Net primary production of a grassland community of Canchipur (Manipur), India. *Indian J Environmental and Ecoplanning* 2001; **4**: 321-238.
10. Angom Daisy, Gupta Asha. Biological spectrum of Keibul Lamjao National Park (KLNP), Manipur, India, *J Curr Sci* 2005; **9(1)** : 125-132.
11. Angom Daisy, Gupta Asha. Utilization of plant Resources by peripheral communities of Keibul Lamjao National Park (KLNP) area. Proceedings of International Conference on Wetland and Aquatic Resources, 1999, Nainital, India.
12. Gee EP. Report on the status of the Brow-antlered deer of Manipur (India). *Bombay Nat Hist Soc* 1960; **57(3)** : 597-617.

13. Milner C, Hughes RE. Methods for the measurement of the primary production of grassland. Oxford: Blackwell Scientific Publications, 1968.

14. Sims PL, Singh JS. Herbage dynamics and net primary production in certain ungrazed and grazed grassland in North America, In: French NR, editor. Preliminary analysis of structure and function in grasslands. Fort Collins: Colorado State University, 1971.

15. Sims PL, Singh JS. The structure and function of ten western North American grasslands III. Net primary production, turnover and efficiencies of energy capture and water use. *J Ecol* 1978; **66** : 573-597.

16. Sims PL, Singh JS. The structure and function of ten western North American grasslands IV. Compartmental transfer and energy flow within the ecosystem. *J Ecol* 1978; **66**: 983-1009.

17. Sah VK, Ram J. Biomass dynamics, species diversity and net primary production in a temperate grasslands of Central Himalaya, India *Trop Ecol* 1989; **30(2)** : 294-302.

18. Pathak PS, Rai P. Production efficiency of three principal grasses in pure and mixed swards. *Int Ecol Environ Sci* 1990; **16(2 and 3)** : 169-170.

19. Gupta SR, Sinha A, Rana RS. Biomass dynamics and nutrient cycling in a sodic soil. *Int J Ecol Environ Sci* 1990; **16(1)**: 57-70.

20. Ambasht RS. A text book of plant Ecology. Varanasi: Student's Friends and Co. 1969.

21. Shankar V, Velayudhan KC, Kanodia KC. Primary productivity, compartmental transfer and system transfer functions in *Chrysopogon fulvus* grasslands. *Ann Arid Zone* 1978; **17** : 30-40.

22. Gupta SR, Mishra GP. Seasonal variation in ground biomass net primary productivity and dry matter dynamics in a *Themeda quadrivalvis* type of grassland community at Jhansi, India. *Int J Ecol Environ Sci* 1983; **9(3)** : 123-132.

23. Singh JS, Yadava PS. Seasonal variation in composition, plant biomass and net community production in grassland at Varanasi. Ph.D. Thesis. Banaras Hindu Univ, Varanasi, 1974.

24. Sah VK, Saxena AK, Singh V. Seasonal variation in plant biomass and net primary productivity of grazing lands in the forest zone of Garhwal Himalaya. *Trop Ecol* 1994; **35(1)** : 115-131.

25. Radhapyari Devi A. Comparative study of net primary production and nutrient status in grasslands of Canchipur, Manipur. Ph.D. Thesis. Manipur University, Manipur, 1995.

26. Manoj D, Govind GR, Pramod K. Primary productivity and system transfer functions in an alpine grassland of Western Garhwal Himalaya. *Trop Ecol* 2000; **41(1)** : 99-101.

27. Singh AK. Structure and primary net production and mineral contents of two grassland communities of Chakia Hills, Varanasi. Ph.D. Thesis. Banaras Hindu University, Varanasi, 1972.

28. Padhan S, Mohanty RK. Above ground biomass, primary production and chlorophyll content of grassland exposed to steel plant waste. *Trop Ecol* 1993; **34(1)** : 93-101.

29. Joshi SP, Srivastava MM. Effect of grazing on species composition, diversity and productivity in a high altitude pasture in Garhwal Himalaya. *Int J Ecol Environ Sci* 1998; **14** : 221-227.

30. Mall LP, Bilore SK. Dry matter structure and its dynamics in *Sehima* grassland community I. Dry matter structure. *Trop Ecol* 1974; **15(1 and 2)** : 108-118.

31. Pandey N, Bhatt AB. Climatic and topographic influences on net primary production in undergrazed and ungrazed conditions in an alpine grazing land of Garhwal Himalaya. *Indian J Forestry* 1998; **21 (4)** : 387-391.

32. Trivedi BK, Mishra GP. Seasonal variation in species composition, plant biomass and net primary productivity of two grasslands in *Sehima-Dichanthium* cover type. *Trop Ecol* 1979; **20(1)** : 114-125.

33. Billore SK, Mall LP. Nutrient composition and inventory in a tropical grassland. *Plant and Soil* 1976; **45** : 509-520.

34. Yadav PS, Kakati LN. Biomass dynamics and net primary productivity in grassland community at Imphal *Int J Biometeorol* 1984; **28** : 123-145.

35. Joshi SK, Patil DP, Bahera N. Primary production of herbaceous layer in a tropical deciduous forest in Orissa, India. *Trop Ecol* 1990; **31(2)** : 73-83.

36. Singh JS. Structure and function of tropical grassland vegetation of India. *Pol Ecol Stud* 1976; **2(2)** : 17-34.

37. Bawa R. Biomass dynamics of Himalayan grasslands. *Int Ecol Environ Sci* 1995; **21(1)** : 25-36.

38. Gill GS. Herbage dynamic and seasonality of primary productivity at Pilani, Rajasthan. PhD. Thesis. Birla Institute of Technology and Science, Pilani, Rajasthan, 1975.

39. Angom Daisy, Gupta Asha. Vegetational analysis of grasslands of Keibul Lamjao National Park (KLNP), Manipur, India. *Eco Env and Cons* 2006; **12 (3)** : 453-464.

Proc. Nat. Acad. Sci. India, Sect. B, Vol. 78, Spl. Issue, 2008

Role of aquatic macrophytes in arsenic phytoremediation in wetlands

RUDRA D. TRIPATHI*, SEEMA MISHRA and SUDHAKAR SRIVASTAVA

Ecotoxicology and Bioremediation Group, National Botanical Research Institute, Rana Pratap Marg, Lucknow-226001, India.

**e-mail : tripathi_rd@rediffmail.com*

Abstract

Arsenic toxicity has emerged as a serious problem during last few decades. Entry of arsenic to humans via drinking water and crop plants like rice might prove harmful. As an environment-friendly and cost-effective technology, phytoremediation may be used effectively to remediate the contaminated areas. Suitable plants include arsenic hyperaccumulating aquatic plants that are widely distributed, show fast growth and good biomass. Recent biochemical and molecular studies have revealed many of the processes and gene products involved in the arsenic detoxification that may be used for genetic engineering approaches to improve arsenic accumulation ability of the plants. This review focuses on the problem of arsenic contamination, the relevance of phytoremediation as a solution, importance and strategies of aquatic plants for the purpose and probable biotechnological solutions.

Key words: aquatic plants, arsenic, phytoremediation, rice

सारांश

पिछले कुछ एक दशको मे आर्सेनिक विषाक्तता एक गभीर समस्या के रूप मे उभरकर आई है। पीने के पानी व धान जैसी फसलो के माध्यम से मानव शरीर में आर्सेनिक का पहुंचना दुष्प्रभावी हो सकता है। वनस्पति परिवेशोद्वार एक पर्यावरण मित्रवत एव सस्ती तकनीक के रूप में संदूषित स्थानो के उपचार हेतु प्रभावी हो सकता है। कुछ आर्सेनिक के अति संग्राहक जलीय पौधे, जो सर्वत्र पाये जाते है और तीव्र गति से बढते हुये काफी जैवभार दर्शाते है वनस्पति परिवेषोद्वार के लिये उपयुक्त होते है। हाल के जैव–रसायनिक एवं आणविक अध्ययनो से पौधो मे आर्सेनिक अविशाक्तिकरण मे प्रयुक्त अनेकों प्रक्रियाओ एवं जीन उत्पादों का पता चला है जिनका प्रयोग जैव अभियंत्रिकी के माध्यम से पौधो में आर्सेनिक संग्रहण क्षमता बढाने में किया जा सकता है। यह लेख आर्सेनिक प्रदूषण की समस्या, वनस्पति परिवेषोद्वार द्वारा समाधान की सभावनाओं तथा इस परिप्रेक्ष में जलीय पौधो के महत्व एव उपयोगिता और जैव तकनीकी समाधानो पर प्रकाश डालता है।

सांकेतिक शब्द : जलीय पौधे, आर्सेनिक, वनस्पति परिवेषोद्वार, धान।

Introduction

Arsenic (As) is a ubiquitous element that ranks 20th in the abundance in the earth crust, 14th in the seawater and 12th in the human body[1]. The permissible limit of As in drinking water is 10 mg L^{-1} [2]. However, very high levels of As contamination of groundwater and its health impact on humans have been reported from 23 countries of the world [3]. The magnitude of this problem is severe in Bangladesh[4-9] followed by West Bengal, India[10-13] and China[14, 15]. In recent years evidence of As contaminated groundwater has also emerged in other Asian countries including: Cambodia, Mayanmar, Pakistan, Nepal, Vietnam and Kurdistan province of Iran[16-20]. Recently high levels of As in the groundwater in other states of India, such as Bihar[21], Jharkhand, Assam[22] and Uttar Pradesh[23] have been found. It is speculated that in the Ganga-Meghna-Brahmaputra plains, covering an area of 570000 km^2, over 450 million people might be at risk from groundwater As contamination[22].

The sources of As contamination in ground water are both natural (through dissolution of As compounds adsorbed onto the pyrite ores into the water by geothermal, geohydrological and biogeochemical factors) and anthropogenic, such as processing of varieties of ores like Cu, Au, Ni, and Zn[24], insecticides and herbicides[25], As-based wood preservatives[26], feed additives in various metal alloys and in mining[1], power generation by the burning of As contaminated coal[27] and semiconductor and glass manufacturing units[24]. Several studies have shown that volcanoes are the important natural sources of As especially in the southern hemisphere[28, 29].

It has been reported that groundwater from shallow tube wells (12-33 m) contain considerably high amount of As whereas, the water from deep tube wells (200-300 m) contain low amount of As (<50 μg L^{-1}) [30]. The subsurface mobilization of As is caused by the combination of chemical, physical and microbial factors.

Various theories have been proposed to explain the mechanism of As mobilization[3]. Of these, the important theories are the pyrite oxidation and oxy-hydroxide reduction[30]. Alluvial and deltaic environments are mostly characterized by reducing conditions[31], hence As^{V} is reduced to As^{III} and adsorbed As^{V} is released as As^{III}.

Arsenic can also enter into the food chain causing wide spread distribution throughout the plant and animal kingdoms. Both long and short term exposures are found to be hazardous and can lead to skin, bladder, lung and prostate cancers, cardiovascular diseases, diabetes, anemia as well as reproductive, developmental, immunological and neurological effects[1, 32-35].

Arsenic phytotoxicity

The phytotoxicity of As is affected considerably by its chemical form. Arsenic exists in a number of inorganic and organic forms, however the two most prevalent ones include inorganic arsenite (As^{III}) and arsenate (As^{V}). Inorganic arsenicals are considered more toxic than organic ones and toxicity of As decreases in order: arsine>inorganic As^{III}>organic As^{III}>inorganic As^{V}>organic As^{V}>arsonium compounds. Arsenicals can cause damage to DNA by inhibiting enzymes involved in DNA repair. Arsenite is a weak mutagen but a potent comutagen. Since As^{V} is a phosphate analogue, it has been reported to replace P in the phosphate groups of DNA[36]. Arsenate affects the phosphate metabolism of plants and disrupts energy flows due to replacement of P by As in ATP by forming unstable ADP-As complexes. Arsenite behaves more as a metal ion and shows high affinity for -SH groups of proteins and enzymes; consequently disturbing the biochemical functioning of cell leading to cell death[37].

The presence of As in irrigation water or soil at an elevated level has been reported to hamper normal growth of plants with a number of toxicity symptoms such as reduction of root and shoot biomass[38, 39], wilting and necrosis of leaf tips and margins[40-42] and lower fruit and grain yield[41, 43-46]. The total N, root nodulation and dry weight of plants have been found to be reduced by As in *Pisum sativum*[47]. Several enzymes from diverse metabolic pathways including porphyrin biosynthesis are inhibited by arsenicals. Inhibition of glutamate dehydrogenase from *Vigna sinensis*[48], a-ketoglutarate oxidase from sweet potato[49], and nitrate reductase in rice[50, 51] has also been demonstrated upon As exposure.

Recent study on *Hydrilla verticillata* demonstrated that at higher exposure concentrations, As^{V} (250 μM) and As^{III} (25 μM) decreased the biomass and photosynthetic pigments of the plants and impaired uptake of nutrients such as P, Fe, Cu, and Mn. Both As^{V} and As^{III} enhanced levels of reactive oxygen species and peroxidation of membrane lipids. As^{III} was found to be more toxic, which was supposed to be due to its rapid influx in addition to its higher reactivity as compared to As^{V} [52]. Similar results were observed by Hartley-Whitaker *et al.* [53] in *Holcus lanatus*, where uptake of As^{V} at a lower rate in metallicolous populations resulted in reduced toxicity as compared to non-metallicolous populations. Plants of *Ceratophyllum demersum* also show toxicity to As^{V} exposure as the concentration and duration of exposure increases. At maximum exposure of 250 μM As^{V} on longer durations, plants showed significant decline in level of biomass and increase in the level of superoxide radicals, hydrogen peroxide, lipid peroxidation and ion leakage.

Abedin *et al.*[54, 55] studied effect of various As concentrations on growth and yield of rice plants. They reported decrease in plant height, root biomass, number of filled spikelets, and grain yield when rice plants were exposed to As^{V} in concentration range of 20-800 μg L^{-1}. However in a different study, supply of up to 500 μg As L^{-1} was found to have no significant effects on dry weight of shoots and roots in rice plants [56]. Jha and Dubey [57] showed an increase in reducing, non-reducing and total soluble sugars, an increased conversion of non-reducing to reducing sugars and alterations in activity of starch degrading enzymes in two varieties (Malviya-36 and Pant-12) of rice upon exposure to As^{III} (25 and 50 μM) for duration of 10-20 d. Further, an increase in the level of RNA, proteins and proline accompanied with a decline in the level of free amino acid pool was also noticed[58]. In a pot experiment, Williams *et al.* [59] found reduced husk and grain yield in rice plants exposed to 100 μg As g^{-1} soil. Arsenic exposure resulted in increased grain C and N status but decreased C:N ratio and P status. Thus As exposure impairs physiology and yield of rice plants.

Arsenic phytoremediation prospects

Conventional remediation options for As include adsorption, ion exchange, precipitation-coagulation, membrane filtration, permeable reactive methods, lime softening, electro-dialysis etc. [3, 60]. However, these

are not cost-effective and thus are not affordable by the common people of poor countries. These difficulties related with conventional methods on one hand and, improved knowledge of the mechanisms of uptake, transport, tolerance and exclusion of heavy metals in microorganisms and plants on the other, have promoted the development of a new technology, named phytoremediation [61-67]. Phytoremediation is a group of technologies that use plants to reduce, remove, degrade or immobilize environmental toxins, primarily those of anthropogenic origin, with the aim of restoring the area to a condition useable for private or public operations. The technique is appealing because it is relatively inexpensive and aesthetically pleasing. Benefits stemming from the use of phytoremediation include *in situ* application, passive, solar-driven nature and applicability to a wide range of metals, radionuclides and organics.

Hyperaccumulator plants, which accumulate significantly high amounts of metals or metalloids in their shoot without showing any severe toxicity compared to non-accumulators [61, 68] are the attractive candidates for phytoremediation [64]. Various aquatic macrophytes like *Ceratophyllum demersum, Rorippa nasturtium-aquaticum, Eigeria densa, Lemna gibba* etc. [69, 70] are known to be hyperaccumulators of As and accumulate more than 1000 µg As g^{-1} dw (0.1% of dw). Various species of *Pteris* [71] including *P. vittata* [72, 73] are also the potential As hyperaccumulators. In a pilot-scale demonstration, the use of *P. vittata* for removal of As from drinking water using a continuous flow phytofiltration system has been demonstrated. Over the course of a 3-month demonstration period, the system consistently produced water having an As concentration less than the detection limit of 2 µg L^{-1}, at flow rates as high as 1900 L per day for a total treated water volume of approximately 60,000 L [74]. These results demonstrate that phytofiltration might provide the basis for a solar-powered hydroponic technique to enable small-scale cleanup of As-contaminated drinking water.

Metalloid accumulation by aquatic plants

Hydrilla verticillata showed good potential for As phytoremediation in various studies. It is an invasive aquatic weed that is widely distributed in Europe, Asia, Australia, New Zealand, the Pacific Islands, Africa, South America, and North America[75] and shows fast growth. It has been demonstrated[76] that *Hydrilla* showed the maximum bioconcentration factor for As accumulation among various plants collected from natural waters. A field survey of various aquatic plants, collected from a fly-ash affected site, for As accumulation potential also demonstrated *Hydrilla* plants to be most efficient accumulator of As[77]. In a recent study by Srivastava *et al.*[52] accumulation of As by hydrilla plants correlated to both concentration and duration of the treatment. However, it varied depending on the species of As. The rate of uptake and total As accumulation was higher in plants exposed to As^{III} compared to As^{V}. The percent accumulation of As increased from 10% after 1 d to 44% after 4 d in plants exposed to As^{V} (at 250 µM; Figure 1 A), while it increased from 15% to 57% in As^{III}-exposed plants (at 25 µM; Figure 1 B) after similar durations. Maximum accumulation of As after 7 d was higher in plants exposed to As^{III} (315 µg g^{-1} dw at 25 µM) compared to As^{V} (205 µg g^{-1} dw at 250 µM) although the As^{III} concentration was 10 times lower than that of As^{V}. Although the level of As accumulation was lower than

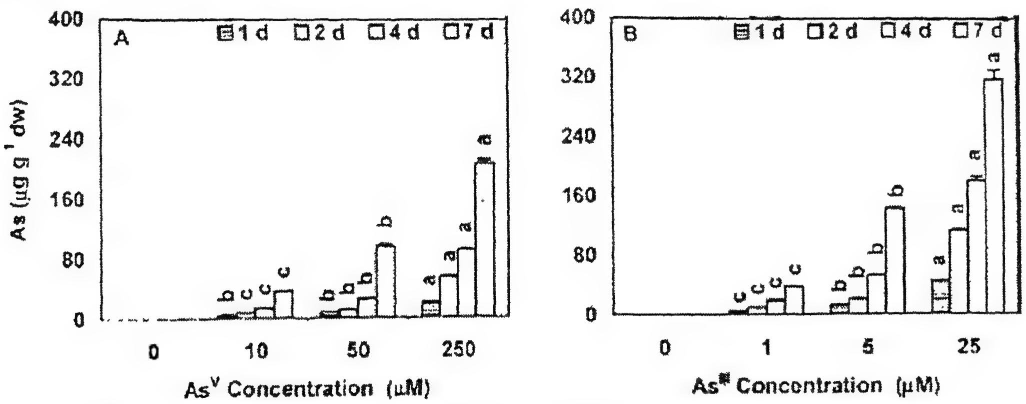


Fig. 1 - Level of arsenic in *Hydrilla verticillate* exposed to different concentrations of arsenate (A) and arsenite (B) for various exposure periods (mean ± SD, n=6). ANOVA significant at $p < 0.01$. Different letters indicate significantly different values at a particular duration (DMRT, $p < 0.05$).

the prescribed limit of hyperaccumulation (1000 μg g^{-1} dw), plants were suggested to be suitable for phytoremediation purposes considering their fast growth and high biomass accumulation in a short period. In addition, *Hydrilla* is found almost everywhere in world, hence is applicable to a wide range of habitat. Thus, use of *Hydrilla* may avoid the habitat problem of As hyperaccumulator fern like *Pteris vittata*.

Arsenic concentrations in freshwater macrophytes were examined in a group of lakes contaminated by the discharge of mine tailings near Yellowknife, N.W.T. lakes (up to 18650 μg As g^{-1} in sediments). Macrophytes like *Potamogeton pectinatus, Typha latifolia, Equisetum fluviatile, Myriophyllum exalbescens* accumulated different levels of As (μg g^{-1} dw), with maximum values of 4990, 136, 962, 255, respectively, thus submerged species accumulated higher levels of As than the emergents[78]. Plants of *Ceratophyllum demersum, Lagarosiphon major* and *Eigeria densa*, growing in river water containing As at 30-80 μg L^{-1} contained 500-1500 μg As g^{-1} dw, which represents a BCF of 10000 or more [79-81]. Robinson *et al.* [82] reported >1000 μg As accumulation g^{-1} dw in samples of *Eigeria densa* and *Ceratophyllum demersum* growing in river system. A survery of watercress (*Rorippa nasturtium-aquaticum*) revealed concentration as high as 1766 μg As g^{-1} dw in the shoots [83]. Robinson *et al.* [70] investigated 28 macrophytes for their As accumulation potential, collected from As contaminated Taupo river, New Zealand having As concentrations 10 to 100 μg L^{-1} and reported that many aquatic macrophytes, such as *Ceratophyllum demersum, Alisma plantago aquatica, Eigeria densa, Elodea canadensis, Juncus sp., Myriophyllum propinaquum, Potamogeton orchreatus* etc. accumulated significant amounts of As.

In recent investigations on *Ceratophyllum demersum* plants for As accumulation potential upon exposure to various concentrations of As^{V} (0-250 μM) for 1-7 day, plants showed significant As accumulation in a concentration duration dependent manner[84]. Maximum As accumulation (525 μg g^{-1} dw) was noticed at 250 μM after 7 d (Figure 2 A). The accumulation of As by *Ceratohyllum demersum* in this study was found to be significantly higher than that found in other aquatic plants such as *Rorippa nasturtium-aquaticum, Myriophyllum propinquum* and *Hydrilla verticillata* [52, 70]. However, it was lower than that reported in an earlier study on *C. demersum* [70]. To, see whether lower As accumulation by *C. demersum* plants in the present study was due to presence of phosphate (about 9.6 mg L^{-1}) in the nutrient medium used for the culture of plants, phosphate concentrations were changed from 0.64 to 640 mg L^{-1} at 10 μM As^{V} in a separate experiment. As expected, decrease in As accumulation with increasing phosphate concentration was noticed (Figure 2 B).

Lemna gibba has also been reported to hyperaccumulate As and this plant has been suggested to act as a preliminary bioindicator for As transfer from substrate to plants[69]. The study on *L. gibba* [85] demonstrated that accumulation of As in plants exposed to As^{V} or As^{III} decreased with the increase in the phosphate concentration, however the effect was more pronounced in plants exposed to As^{V} than As^{III}. Arsenic

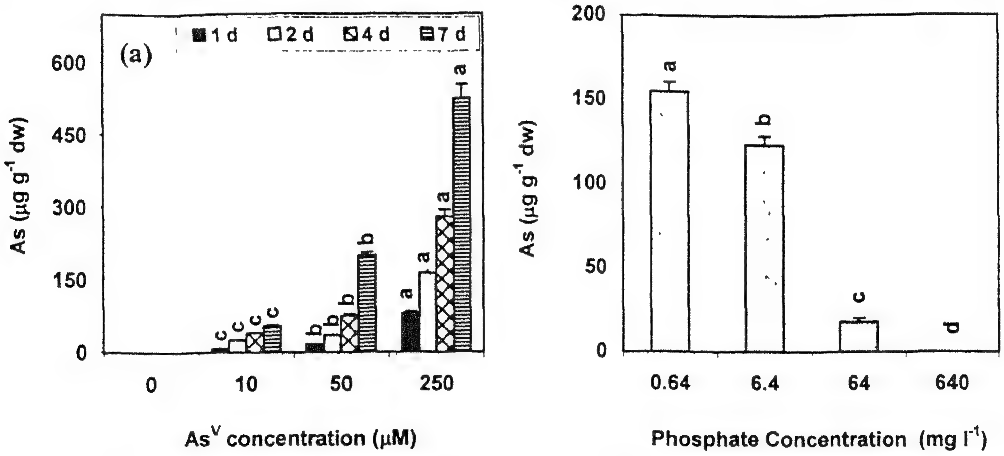


Fig. 2 - Accumulation of arsenic by *Ceratophyllum demersum* exposed to different concentrations and durations (A) and in plants exposed to 10 μM arsenate for 7d in the presence of increasing concentrations of phosphate (B). All the values are means of triplicates ± SD. ANOVA significant at $p < 0.01$. Different letters indicate significantly different values at a particular duration (DMRT, $p < 0.05$).

accumulation coefficients in *L. gibba* were 10 times as much as the background concentrations and it accumulated As up to 500 μg g^{-1} dw at 10 mg L^{-1} and 2100 μg g^{-1} dw at 1000 mg L^{-1}As, however accumulation decreased (from 2100 to 1100 μg g^{-1} dw at 1000 μg L^{-1} As) when P concentration increased from 14 to 40000 μg L^{-1}. Plants of *Salvinia minima* have been found to tolerate 200 μM As and to accumulate up to 500 μg As g^{-1} dw[86].

Total As levels in marine organisms are much higher than those detected in seawater. Dimethylarsinoylribosides (arsenosugars) are a dominant species in marine algae. Dimethylarsinic acid (DMA), inorganic As [As^{III} + As^{V}] and arsenobetaine were also detected in algae [87, 88]. Marine organisms have the ability to accumulate and transform As into less toxic or non-toxic organic As compounds [32, 89], yielding As concentrations 3-4 orders of magnitude higher than in seawater. Marine algae, particularly brown macroalgae commonly contain As at concentrations 10000-fold higher than those in their ambient seawater [90].

Arsenic uptake, translocation and speciation in the plants

Arsenate is known to be taken up by plants via the high affinity phosphate transport systems as an analogue of phosphate [54, 91, 92]. Transport of As^{III} is known to occur through aquaglyceroporins as a neutral molecule in bacteria, yeast and also in plants [54, 93, 94]. Uptake of both As^{V} and As^{III} is an active process, described by two additive hyperbolic functions over high affinity (low concentration) and low affinity (high concentration) ranges [54]. Uptake of organic species of As, DMA and MMA is also known to take place though at a lower rate than inorganic ones [95], however role of any transporter has not yet been implicated.

X-ray absorption spectroscopy (XAS) and High performance liquid chromatography-inductively coupled plasma mass spectrometry (HPLC-ICP-MS) studies on sporophytes of *Pteris vittata* have shown that As is translocated to the shoot mainly as As^{V} and is stored in the fronds as inorganic As^{III} [96-100]. Recent X-ray analyses on intact tissue from *Pteris vittata* provided strong evidence that, mainly, untransformed As^{V} is transported to shoots, and reduction of As^{V} was suggested to involve thiolates in the form of a cylinder around the As^{V} in the veins[100].

Inside the plant, various transformations and distribution take place depending on the plant species. Arsenate in the plant is reduced to As^{III} and then methylated in the leaves, accompanied by the induction of arsenite methyltransferase activities [37, 101, 102]. Studies on *Pteris vittata* have shown that almost all As in this plant is present as inorganic forms, with much greater amounts of As^{III} in the fronds (47-80%) than in the roots (8.3%) [72, 103, 104]. Recent work of Pickering *et al.* [100] on sporophytes of *Pteris vittata* showed that roots predominantly contained As^{V} (90%), with a minor component of As^{III} (10%), rachis showed a mixture of 24% As^{V} and 76% As^{III} while leaves predominantly had As^{III} (95%). Similar results have also been reported in *Pityrogramma calomelanos*[105]. These findings suggest that terrestrial plants readily reduce As^{V} to As^{III} but show limited methylation of As[37].

By contrast, a large number of As compounds, like monomethylarsonic acid (MMAA), dimethylarsinic acid (DMAA), trimethylarsine oxide (TMAO), tetramethylarsonium ion (TETRA), arsenocholine (AsC) and some inorganic As (As^{III} and As^{V}) can also be found in marine organisms, but generally in significantly lower amounts compared to AsB or arsenosugars[32, 89, 106]. Several research groups have established that arsenobetaine (AsB) is the major As species found in animal tissues, while in plants like algae, the most frequently occurring As species are arsenosugars[107-110]. It has been proposed that marine algae convert oceanic inorganic As via methylation steps and adenosylation to arsenosugars (dimethylarsinylriboside derivatives), which are abundant in marine algae. Then, the arsenosugars undergo a partial degradation, further methylation and oxidation steps leading to the formation of the biosynthetic end-product arsenobetaine[111]. However, the synthesis of arsenobetaine does not take place within marine algae. Maeda *et al.*[112] performed a series of studies on the green alga *Chlorella vulgaris*, and found that freshwater algae were able to methylate As compounds.

Zheng *et al.* [113] studied two submerged freshwater plant samples, *Ceratophyllum demersum* and *Elatine triandra*, a terrestrial plant (*Eleocharis spp.*) and an emergent plant (*Typha latifolia*). High concentrations of As were detected in the freshwater plants. Except for *Typha latifolia* leaves the investigated plants showed significantly elevated As concentrations (from 21 to 117 μg g^{-1} dw) compared to commonly observed As concentrations in plants,

ranging from 0.2 to 2.0 μg g^{-1}_{dw}[114]. The highest As concentration was observed in the root of sedge (*Eleocharis spp.*), which was about five times higher than in the stem of the same species. The distribution of As compounds depended on the plant species. In the terrestrial plant Eleocharis spp. (either in stem or in root), organic compounds, MMA (0.3%- 0.7%), DMA (0.7% in stem, not found in root), TMAO (0.6% in root, not found in stem), and TETRA (1.2% in stem, not found in root) were detected at trace levels. However, inorganic As compounds predominated in the extract (ca. 98% of the total As in the extract), of which As^{III}, was the major species (60%-68%). In the emergent plant (Typha latifolia) and submerged plants (Elatine triandra and Ceratophyllum demersum), inorganic As compounds were predominant as well (ca. 92% for submerged plants; 69% for emergent plant). However, in these plants, As^{V} was the major species. Particularly, for the submerged plants, the ratio of As^{V} to As^{III} was ca. 13 for the lake weed (*Elatine triandra*), and 5.6 for the river weed (*Ceratophyllum demersum*), suggesting that the hypothesis of reduction and storing As as As^{III} may not be applied to these plants. A variety of organic compounds, such as the simple methylated MMA and DMA, TMAO and TETRA, as well as an unknown As compound U (probably an arsenosugar), were detected in plant samples. However, no AB and AC were detected in any investigated samples, confirming results from Kuehnelt *et al.*[115]. About 30% of the total As in the extract of emergent plant (*Typha latifolia*) were organic As compounds. Approximately, about 15% of the total As was TMAO, and ca. 4 % TETRA. In the two submerged plants (*Elatine triandra* and *Ceratophyllum demersum*), the organic As compounds accounted for about 8% of the total As in the extracts. These results indicate that emergent and submerged plants have a certain ability of inorganic As methylation, which may contribute to the detoxification process. An unknown As compound (U) was detected in submerged plant of *Elatine triandra* and *Ceratophyllum demersum*, which was speculated to be glycerol-ribose arsenosugar. Koch *et al.* [116] also reported the presence of arsenosugars in submerged plants collected from Yellowknife, Canada. However, the origin of arsenosugars in such plants is not established yet. Whether it is a result of the uptake of this species from the environment, synthesis by the plants or due to the contamination with other organisms remains to be elucidated.

Arsenic accumulation and role of iron plaque formation in root arsenic immobilization in wetland plants

Arsenic species can enter into edible tissues of food crops through use of As-contaminated irrigation water[95] or As-based pesticides[59]. Arsenic accumulation in rice is of particular concern because rice needs more irrigation and also faces greater risk of As accumulation due to anoxic conditions in rice fields, most of the As remains as As^{III}, which is more readily taken up by the plants. Further, rice is a major staple crop of world and is extensively cultivated in areas, which are most severely contaminated with As, including India, Bangladesh, China and Taiwan. Accumulatoin of As in rice depends on many factors such as climate, soil type and rice variety. Onken and Hossner [117] grew rice (*Oryza sativa*) in two soil types simulated with up to 45 μg As^{III} or As^{V} g^{-1} for 60 days. The As concentration of rice plants correlated with the mean soil solution As^{V} concentration in the clay soil and to the mean soil solution As^{III} for the silt loam. The rate of As uptake by plants increased as the rate of plant growth increased. Abedin *et al.* [54] studied uptake kinetics of different species of As in rice plants. DMA and MMA showed much lower rates of uptake than As^{V} and As^{III}. Phosphate application did not affect As^{III} uptake and toxicity but reduced As^{V} uptake and toxicity. DMA and MMA also showed restricted translocation with 0%-5% of total As in rice straw being DMA. However, others show that DMA may be major component of As in rice grain [118, 119]. When irrigated with As^{V} contaminated water, rice plants have been found to accumulate As to levels of 1.8 μg g^{-1} dw in seeds and up to 92 μg g^{-1} As in rice straw[54, 120].

Williams *et al.* [59] conducted a survey of As speciation in different rice varieties from different parts of the globe and found that USA long grain rice had the highest mean grain As level of 0.26 μg g^{-1} dw and the highest grain As (0.40 μg g^{-1} dw). The mean As level from Bangladeshi rice was 0.13 μg g^{-1} dw, in a range from 0.03 to 0.30 μg g^{-1} dw. However, large variability exists in the mean As values of other Bangladeshi rice surveys, 0.10-0.95 μg g^{-1} dw with the maximum level of As reported in a rice grain sample being 2.05 μg g^{-1} dw [121]. European rice had a mean As level of 0.18 μg g^{-1} dw, in a range from 0.13 to 0.22 μg g^{-1} dw. Basmati rice from India possessed the lowest mean As level at 0.05 μg g^{-1} dw, with

little variation, only in the range of 0.03 to 0.08 µg g^{-1} dw. The main As species detected in the rice grain were As^{III}, DMA^{V}, and As^{V}. In European, Bangladeshi, and Indian rice 64%, 80%, and 81%, respectively, of the recovered As was found to be inorganic. In contrast, DMA^{V} was the predominant species in rice from USA, with only 42% of the As being inorganic. In the pot experiments, in all treated plants, grain As rise sharply with increasing shoot As only up to a threshold concentration of 2 mg g^{-1} dw, beyond which grain As plateaus at higher shoot As concentrations. Extensive investigations indicate that As bioavailability in rice is highly dependent on As speciation, which in turn can vary depending on rice cultivar and As in irrigation water[122].

The bioavailability of As in soil is usually affected by physico-chemical properties of Fe. There are a few reports on the effects of interactions between As^{V}, phosphate and iron hydroxides/oxides on As behavior in soil-plant systems. Iron plaque is commonly formed on the surfaces of roots of aquatic plants, including *Oryza sativa, Typha latifolia* and *Phragmites communis*, and is mainly caused by the oxidation of ferrous to ferric iron and the precipitation iron oxide on the root surface[123], promoted by the release of oxygen and oxidants into the rhizosphere[124, 125-127]. The importance of iron plaque in As attenuation in the rhizosphere has been demonstrated in wetland plants such as *Phalaris arundinacea* and *Typha latifolia*[128]. Arsenic and iron concentrations on the root surface were revealed by X-ray absorption spectroscopy and X-ray fluorescence microtomography to be spatially and temporally correlated. X-ray fluorescence microtomography showed that As bound to iron plaque on root surfaces of the aquatic plants *Phalaris arundinacea* and *Typha latifolia* was largely As^{V} [128]. Therefore, iron plaque may also play a role in reducing the toxicity of As contamination in soil-plant systems. Iron plaque may be amorphous or crystalline, in the forms of ferric hydroxides, goethite and lepidocrocite [125, 129]. A recent study showed that iron plaque is composed dominantly of ferrihydrite (63%) with lesser amounts of goethite (32%) and minor level of siderite (5%) [130]. Iron oxides or hydroxides have high affinity for As in soils and other environments [131]. Meng *et al.*[132] found that As^{V} had very strong binding affinity for iron hydroxides. Otte *et al.*[133] showed that iron plaque played an important role in the uptake of As by salt-marsh plants. In a recent study on phosphorus-As interactions in the soil-rice system, Liu *et al.*[56, 134] revealed that P nutrition of rice plants might to some extent control the formation of iron plaque, and this phenomenon, in turn may influence As^{V} uptake by rice plants. Total uptake of As in -P plants (around 150-225 µg g^{-1} dw) was significantly higher than the +P plants (around 50-65 mg g^{-1} dw). In seedlings grown with P, most of the As accumulated in roots and shoots while in -P seedlings, most of As was retained in iron plaque. In -P +As plants, only 2%-3% of the total As was taken up by plants, whereas in +P+As plants, 15%-23% of total As was transported to shoots. This was due to more iron plaque formation on rice roots of -P plants than +P and greater retention of As in iron plaque. Chen *et al.* [135] found that Iron plaque had contrasting effects on the uptake of As^{III} and As^{V} as uptake of As^{III} was enhanced by the presence of iron plaque, but that of As^{V} was dramatically inhibited by the iron plaque.

Arsenic tolerance and detoxification strategies

Some plants can survive and even grow well when they accumulate high concentrations of toxic elements, as is the case of the hyperaccumulator plants, while others can tolerate exceedingly high metal concentrations through their reduced uptake, as in case of hypertolerant plants. Plants adopt a range of strategies to combat As toxicity. These can be broadly categorized in two levels. Primary level refers to minimization of free metalloid ion concentration. This might operate through transformation of more toxic inorganic As species to less toxic organic ones or through storage of As in a cellular compartment like vacuole[113, 136]. Secondary level of detoxification involves protection against oxidative stress, induced by free metalloid ion, through a complex antioxidant system[137].

Transformation of inorganic As species to organic forms has been shown to be a common phenomenon in marine ecosystems[32] and contributes significantly to As detoxification. Organic forms of As have also been detected in some aquatic[113] and terrestrial[102] plants and it seems that As detoxification through transformation to organic forms may also operate in plants. However, this remains to be elucidated.

Reduction of As^{V} to As^{III} and complextion of As^{III} with glutathione (GSH) and phytochelatins (PCs)

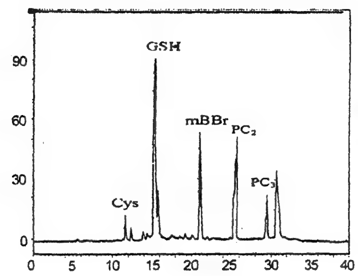
followed by sequestration of these complexes in vacuoles has been considered as a major strategy of As detoxification in plants[136]. The first step of this mechanism i.e. reduction of As^{V} to As^{III} may occur either non-enzymatically or may be catalyzed by the enzyme known as arsenate reductase (AR). Recently, AR genes have been identified in plants, including *Arabidopsis* (AtAsr/AtACR2), *Holcus* (HlAsr), *Pteris* (PvACR2) and rice (OsACR2.1 and OsACR2.2)[136, 138-140]. In addition, biochemical characterization of AR activity has been performed in aquatic plants like *Ceratophyllum demersum*[84]. Increased AR activity in *Halcus lanatus* and *C. demersum* has been suggested to contribute to their As tolerance[136]. Many studies point towards the essential role of PCs in both constitutive and adaptive tolerance to As[141, 142]. And, an increased synthesis of PCs as well as GSH under As stress has been observed in hypertolerant [142, 143], hyperaccumulator [84, 104, 144] as well as non-hyperaccumulator [52, 145] plants. In addition, complexation of As with GSH and PCs has been demonstrated in various plants, such as *Rauvolfia serpentina, Halcus lanatus, Pteris cretica, Helianthus annuus* and *Brassica juncea* [146-150], and appears to contain As^{III}, exclusively.

However hyperaccumulator plant, like *Pteris vittata* shows a rapid influx of As^{V}, reduce it to As^{III} and store it, probably in vacuoles [100], but do not show an adequate production of higher chain phytochelatins as would be expected [104]. On the other hand, Zheng *et al.* [113] found that in some aquatic plants including *Ceratophyllum demersum*, As predominantly existed in the form of As^{V} and suggested that the complexation of As in the form of As^{III} might not be a sole strategy for As detoxification in these plants. However during our study on *Ceratophyllum demersum*, As^{III} chelating peptides have been identified as PC_2 and PC_3 besides some unidentified thiols [84]. The higher level of thiol compounds was in turn modulated by increased activity of cysteine synthase and availability of cysteine during As^{V} exposure. The chelation efficiency of PC-SH towards As was higher on shorter durations and lower As^{V} exposures (about 30% at 50 μM As^{V} after 2 d) that dropped with increase in exposure concentration and duration (14% at 100 μM, after 4 d). A strategy may possibly operate in *Ceratophyllum demersum*, where upon higher As^{V} exposures and high As accumulation, significant increase in activity of γ-glutamyltranspeptidases was noticed that was supposed to be for the degradation of PCs after sequestering As in vacuoles[84]. The lower chelation of As with PCs might then suggest that probably PCs act as shuttles to transport As to vacuoles, where they may probably be degraded and their constituents amino acids may be reutilized for their continuing synthesis. This may explain the low chelation ratio of PC-SH to As as well as possible strategy of As hyperaccumulation. Srivastava *et al.*[52] reported significant increase in cysteine, non-protein thiols (NP-SH), GSH as well as PCs in response to As^{V} and As^{III} in *Hydrilla verticillata*. Increase in all the thiolic constituents was found to be higher in response to As^{III} than As^{V}. Analysis of PCs revealed increasing accumulation of PC_2 and PC_3 with the increase in concentration of both As^{V} and As^{III}. In plants exposed to As^{III}, a maximum of about 39% As was found to be chelated by PCs at 10 μM assuming a stoichiometry of 3 PC-SH to 1 As while in the case of As^{V}-exposed plants, this would approach a maximum of 35% As at 50 μM. However, it may not be ruled out that there may be some other novel mechanisms of As tolerance in plants. A time dependent analysis of As speciation and PC synthesis at subcellular level might improve the understanding of As detoxification mechanisms.

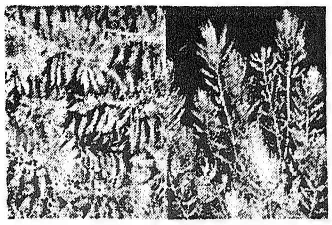
For efficient tolerance to As, its chelation or transformation at primary level needs to be complemented at secondary level through stimulated antioxidant system because presence of free metalloid ion may initiate oxidative reactions. Thus, to avoid oxidative stress, alleviation of oxidants is an important strategy, which is provided by a number of antioxidant enzymes, such as superoxide dismutase (SOD), ascorbate peroxidase (APX), guaiacol peroxidase (GPX), catalase (CAT) and glutathione reductase (GR) and metabolites like cysteine and glutathione (GSH). GSH is predominant non-protein thiol (NP-SH) in the plant cell. High thiol content enables metabolites to function in free radical and ROS detoxification. ROS species are reductively detoxified by concomitant oxidation of sulfhydryl moieties to disulfides[151, 152].

Mylona *et al.*[153] has hypothesized that As induces various detoxification enzymes. This occurs because the As exposure rapidly depletes the pool of GSH, leading to a rise in steady state concentration of ROS. This results in changes in the equilibrium of ROS and antioxidant enzymes that leads to induction of the antioxidant defense system including rise in total GSH levels.

In a study on *Hydrilla*[52], the activity of various enzymes viz., SOD, APX, GPX, CAT and GR in-



HPLC profile showing synthesis of metal binding peptides, the phytochelatins (PCs)in aquatic plant *C. demersum* in response to As exposure .



Aquatic macrophytes , such as *Ceratophyllum demersum, Hydrilla verticillata etc. are* good candidate for phytoremediation purposes

The gene responsible for synthesis of PCs, known as phytochelatin synthase (*PCS*) has been cloned from *C. demersum* (*CdPCS1*). Overexpression of *CdPCS1* in transgenic aquatic/terrestrial plants may show enhanced potential for remediation of metal/metalloid contaminated sites through increased synthesis of phytochelatins.

Arsenic contamination of water and soil

Aquatic plants such as *Ceratophyllum demersum* and *Hydrilla verticillata* show good potential for Arsenic accumulation and may prove promising candidate for remediation of Arsenic contaminated sites due to fast growth, large surface area, wide distribution and easy harvestibility. They can be used as gene source (as *CdPCS1* etc.) for enhanced phytoremediation potential of transgenic aquatic/terrestrial plants, through genetic engineering.

creased significantly at lower exposures of both As^{V} and As^{III}. However, As^{V} showed a greater increase in the activity of the enzymes as compared to that observed with As^{III}. On the other hand, level of thiols was increased more in response to As^{III} than to As^{V} However, both the systems responded in a coordinated manner to endow plants with tolerance up to 50 µM As^{V}/5 µM As^{III}. Similar results were obtained by Mishra *et al.*[84] on *Ceratophyllum demersum,* which showed modulation of antioxidant system and thiol synthesis and consumption in a coordinated and complementary manner to detoxify As up to a moderate concentration of 50 µM As^{V} until 4 d. Mylona *et al.* [153] demonstrated significant increase in the activity of CAT and SOD in response to As^{V} and As^{III} in different tissues and in different developmental stages of maize. Modulation of mRNA transcripts of CAT, SOD and GST was also observed indicating that both As^{V} and As^{III} modulated the antioxidants at molecular level. The induction of GST was supposed to facilitate the conjugation of As to GSH.

Molecular approaches in arsenic bioremediation

Many efforts have been made to increase the phytoremediation efficiency of plants. One of the strategies to improve metalloid remediation was to increase synthesis of chelators such as GSH and PCs. In one study, constitutive overexpression of *AtPCS1* resulted in a substantial increase in As resistance, with a 20-100 times greater biomass in transgenic plants after exposure to As[154]. However, in another case

despite increased PC synthesis, chloroplast-targeted overexpression of *AtPCS1* markedly sensitized transgenic plants to As, whereas cytosolic overexpression of the same gene resulted in increased tolerance[155]. Thus, it appears that overexpression of PCS on its own has limited effects partly due to the limiting supply of essential metabolites such as cysteine, γglutamylcysteine (γ-EC) and GSH, which are needed for the production of PCs [155]. The simultaneous overexpression of enzymes involved in GSH biosynthesis, such as γ-glutamylcysteine synthetase (γ-ECS) and glutathione synthetase (GS), might prove a more successful approach because this will lead to increased levels of GSH and the end-product PCs.

Further, AR might be another important target enzyme because of importance of As^{V} reduction in the detoxification of As [136, 156]. Dhankher *et al.* [138] cloned an AR gene from *A. thaliana* (*AtACR2*) and silenced its expression in roots; RNAi transgenics accumulated 10- to 16-fold more As in the shoots and retained less root As compared with WT plants when grown in the presence of low levels of As^{V}. However, the transgenic lines were more sensitive than WT plants when exposed to high concentrations of As^{V}, probably because of the negative effects of As^{V} on phosphate metabolism. By contrast, Bleeker *et al.*[136] found that *Arabidopsis asr* (equivalent to *AtACR2*) loss-of-function mutants were more As sensitive than WT plants, even to low levels of As^{V}, and showed a five-fold reduction in shoot As. When they overexpressed *AtASR*, the plants showed enhanced tolerance to mildly toxic levels of As^{V} but hypersensitivity to higher concentrations of As^{V} - probably owing to the fast conversion of As^{V} to the more toxic As^{III}. Constitutive overexpression and suppression of AR, therefore, appear to result in plant hypersensitivity to high levels of As^{V}. Thus, to improve As tolerance and As accumulation without affecting phosphate metabolism, overexpression of AR might need to be limited to the roots and might need the simultaneous upregulation of the capacity for As^{III} chelation, root-to-shoot transport and subsequent vacuolar sequestration.

Efficient uptake and translocation from root-to-shoot contribute greatly to hyperaccumulation of As in *Pteris vittata* [72]. This fact emphasizes the importance of the transporters involved in As uptake, root-to-shoot translocation and vacuolar sequestration during hyperaccumulation. For As^{V}, transport is considered to occur through phosphate carriers, however no plant transporter has yet been identified that could mediate transport of As^{III} from root-to-shoot. Pickering *et al.* [146] and Raab *et al.* [150] identified unbound As^{V} and As^{III} in xylem sap of *Brassica juncea* and *Helianthus annuus*, but no As-PC complexes[150]. Thus, Raab *et al.*[150] postulated that As^{V} and As^{III} are the main species that are transported from root-to-shoot, not the As-PC complexes. During the final step of detoxification, inorganic and complexed As can be sequestered into vacuoles. In yeast, vacuolar accumulation of As^{III}-GS_3 complexes is mediated by an ABC-type transporter [157]. In plants, *in vitro* transport of GSH-complexed As^{III} across tonoplast vesicles of *A. thaliana* has been demonstrated [136]. However, no report of *in vivo* transport of either As^{III}-GS_3 or As-PC complexes in plants is available. Similarly, no transport processes that could mediate the vacuolar deposition of inorganic forms of As have been identified. Recently, PC synthase gene from *C. demersum* (*CdPCS1*) has been cloned and bacterial cells transformed with *CdPCS1* have been shown to possess greater tolerance to heavy metals [158]. Currently, tobacco plants transformed with *CdPCS1* are being evaluated by the authors for their arsenic tolerance and remediation potential.

Conclusions and future prospects

Wetland plants hold great promise as a cost-effective remediator of As contaminated water bodies. They cope up with As toxicity through coordinated and complementary response of a number of strategies. Broadly, plants at a primary level attempt to reduce the concentration of free metalloid ion while at a secondary level avoid toxicity caused by free metalloid ions through antioxidants systems. It thus envisages that manipulation of single or small numbers of genes is unlikely to result in plants that resemble natural hyperaccumulators and that the simultaneous optimization of interlinked processes is crucial. However, there might be a need to intervene in the constitutive or organ-specific expression of a number of genes that participate in As uptake, chelator synthesis, vacuolar sequestration and arsenate reduction. This might require the identification of key regulatory genes and the implementation of novel technologies such as trait pyramiding and gene stacking. However for the development of potential wetland phytoremediator plant, the transformation protocols for these plants need to be developed.

Acknowledgements

Authors are thankful to Dr. Rakesh Tuli, Director, National Botanical Research Institute, Lucknow for the facilities provided. This work was supported by CSIR network project (NWP) grant. SM and SS are thankful to Council of Scientific and Industrial Research, New Delhi, India for the award of Senior Research Fellowships.

References

1. Mandal BK, Suzuki KT. Arsenic round the world: a review. *Talanta* 2002; **58** : 201-235.

2. World Health Organization (WHO). Arsenic in Drinking Water. http://www.who.int/inf-fs/en/fact210.html (May 30, 2001).

3. Mondal P, Majumdar CB, Mohanty B. Laboratory based approaches for arsenic remediation from contaminated water: Recent developments. *J Hazar Mater* 2006; **137** : 464-479.

4. Roychowdhury T, Basu GK, Mandal BK, Biswas BK, Samanta G, Chowdhury UK, Chanda CR, Lodh D, Roy SL, Saha KC, Roy S, Kabir S, Quamruzzaman Q, Chakraborti D. Arsenic poisoning in the Ganges delta. *Nature* 1999; **401** : 545-546.

5. Chowdhury UK, Biswas BK, Roychowdhury T, Samanta G, Mandal BK, Basu GK, Chanda CR, Lodh D, Saha KC, Mukherjee SK, Roy S, Quamruzzaman Q, Chakraborti D. Groundwater arsenic contamination in Bangladesh and West Bengal, India. *Environ Health Perspect* 2000; **108**: 393-397.

6. Chowdhury UK, Rahman MM, Mandal BK, Paul K, Lodh D, Biswas BK, Basu GK, Chanda CR, Saha KC, Mukherjee SC, Roy S, Das R, Kaies I, Barua AK, Palit SK, Quamruzzaman Q, Chakraborti D. Groundwater arsenic contamination and human suffering in West Bengal, India and Bangladesh. *Environ Sci* 2001; **8** : 393-415.

7. Smith AH, Arroyo AP, Mazumdar DNG, Konsnett MJ, Harnandez AL, Lingas EO, Beeris M, Smith MM, Moore LE. Arsenic induced skin lesions among Atacameno people in northern Chile despite good nutrition and centuries of exposure. *Environ Health Perspect* 2000; **108** : 617-620.

8. Rahman MM, Chowdhury UK, Mukherjee SC, Mondal BK, Paul K, Lodh D. Chronic arsenic toxicity in Bangladesh and West Bengal, India, a review and commentary. *Clin Toxicol* 2001; **39** : 683-700.

9. Van Geen A, Zheng Y, Versteeg R, Stute M, Horneman A, Dhar R, Steckler M, Gelman A, Small C, Ahsan H, Graziano JH, Hussain I, Ahmed KM. Spatial variability of arsenic in 6000 tube wells in a 25 km^2 area of Bangladesh. *Water Resour Res* 2003; **39(5)** : 1140.

10. Guha Mazumder DN, Haque R, Ghosh N, De BK, Santra A, Chakraborti D, Smith AH. Arsenic levels in drinking water and the prevalance of skin leisons in West Bengal, India. *Int J Epidemiol* 1998; **27** : 871-877.

11. Mandal BK, Roychowdhury T, Samanta G, Mukherjee DP, Chanda CR, Saha KC, Chakraborti D. Impact of safe water for drinking and cooking on five arsenic-affected families for 2 years in West Bengal, India. *Sci Total Environ* 1998; **218** : 185-201.

12. Chakraborti D, Rahman MM, Paul K, Chowdhury UK, Sengupta MK, Lodh D, Chanda CR, Saha KC, Mukherjee SC. Arsenic calamity in the Indian sub-continent-what lessons have been learned? *Talanta* 2002; **58** : 3-22.

13. Rahman MM, Mandal BK, Roychowdhury T, Sengupta MK, Chowdhury UK, Lodh D. Arsenic groundwater contamination and sufferings of people in North 24-Parganas, one of the nine arsenic affected districts of West Bengal India: the seven years study report. *J Environ Sci Health* 2003; **38** : 25-59.

14. Sun GF, Liu S, Li B, Sun XC, Guo X, Qian C. Current situation of endemic arsenicosis in China. *Environ Sci* 2001; **8** : 425-34.

15. XiaY, Liu J. An overview on chronic arsenism via drinking water in PR China. *Toxicology* 2004; **198** : 25- 29.

16. ESCAP-UNICEF-WHO Expert Group Meeting DV. Economic and Social Commission for Asia and the Pacific; geology and health: solving the arsenic crisis in the Asia Pacific Region. ESCAPUNICEF-WHO Expert Group Meeting, Bangkok; May 2-4, 2001.

17. Tendukar N, Bhattacharya P, Mukherjee AB. Managing arsenic for our future. Proceedings of the International Conference on Arsenic in the Asia-Pacific Region, November, 2001, Adelaide, Australia.

18. Berg M, Tran HC, Nguyen TC, Pham MV, Schertenleib R, Giger W. Arsenic contamination of ground water and drinking water in Vietnam: a human threat. *Environ Sci Technol* 2001; **35** : 2621-2626.

19. Shrestha RR, Surestha MP, Upadhyay NP, Pradhan R, Maskey A, Maharjan M. Groundwater arsenic contamination, its health impact and mitigation programme in Nepal. *J Environ Sci Health* 2003; **38** : 185-200.

20. Mosaferi M, Yunesion M, Mesdaghinia A, Naidu A, Nasseri S, Mahvi AH. Arsenic occurrence in drinking water of IR of Iran: the case of Kurdistan Province. In: Ahmed MF, Ali MA, Adeel Z, editors. Fate of arsenic in the environment- Tokyo, Japan: Bangladesh University of Engineering and Technology, Dhaka, Bangladesh and the United Nations University, 2003.

21. Chakraborti D, Mukherjee SC, Pati S, Sengupta MK, Rahman MM, Chowdhury UK, Lodh D, Chanda CR,

Chakraborti AK, Basu GK. Arsenic groundwater contamination in middle Ganga Plain, Bihar, India: a future danger? *Environ Health Persp* 2003; **111** : 1194-1201.

22. Chakraborti D, Sengupta MK, Rahman MM, Ahamed S, Chowdhury UK, Hossain MA. Groundwater arsenic contamination and its health effects in the Ganga-Meghna-Brahmaputra Plain. *J Environ Monit* 2004; **6** : 75N-83N.

23. Ahamed S, Sengupta MK, Mukherjee A, Hossain MA, Das B, Nayak B, Pal A, Mukherjee SC, Pati S, Dutta RN, Chatterjee G, Mukherjee A, Srivastava R, Chakraborti D. Arsenic groundwater contamination and its health effects in the state of Uttar Pradesh in upper and middle Ganga plain, India: A severe danger. *Sci Total Environ* 2006; **370**: 310-322.

24. Leist M, Casey RJ, Caridi D. The management of arsenic wastes: problems and prospects. *J Haz Mater* 2000; **76**: 125-138.

25. Korte NE, Fernando Q. A review of arsenic(III) in groundwater. *Crit Rev Environ Control* 1991; **21** : 1-39.

26. Chen SL, Yeh Sj, Yang MH, Lin TH. Trace-element concentration and arsenic speciation in the well water of a Taiwan area with endemic blackfoot disease. *Biol Trans Elem Res* 1995; **48** : 263-274.

27. McNeill LS, Edwards M. Arsenic removal during precipitative softening. *J Environ Eng* 1997; **123** : 453-460.

28. Nriagu JO. A global assessment of natural sources of atmospheric trace metals. *Nature* 1989; **338** : 47-49.

29. Nriagu JO, Pacyna JM. Quantitative assessment of worldwide contamination of water, air, and soils with trace elements. *Nature* 1988; **333** : 134-139.

30. Hossain MF. Arsenic contamination in Bangladesh - An overview. *Agric Ecosys Environ* 2006; **113** : 1-16.

31. Smedley PL, Kinniburgh DG. A review of the source, behaviour and distribution of arsenic in natural waters. *Appl Geochem* 2002; **17** : 517-568.

32. Cullen WR, Reimer KJ. Arsenic speciation in the environment: *Chem Rev* 1989; **89** : 713-764.

33. NRC (National Research Council). Arsenic in Drinking Water, Washington DC: National Academy Press, 1999.

34. da Silva ALO, Barrocas PRG, Jacob SDC, Moreira JC. Dietary intake and health effects of selected toxic elements. *Braz J Plant Physiol* 2005; **17** : 79-93.

35. Duker AA, Carranaza EJM, Hale M. Arsenic geochemistry and health. *Environ Int* 2005; **31** : 631-641.

36. Patra M, Bhowmik N, Bandopadhyay B, Sharma A. Comparison of mercury, lead and arsenic with respect to genotoxic effects on plant systems and the development of genetic tolerance. *Environ Exp Bot* 2004; **52** : 199-223.

37. Meharg AA, Hartley-Whitaker J. Arsenic uptake and metabolism in arsenic resistant and non-resistant plant species. *New Phytol* 2002; **154** : 29-43.

38. Tang T, Miller DM. Growth and tissue composition of rice grown in soil treated with inorganic copper, nickel, and arsenic. *Commun Soil Sci Plant Anal* 1991; **22** : 2037-2045.

39. Carbonell-Barrachina AA, Aarabi MA, DeLaune RD, Gambrell RP, Patrick WH. The influence of arsenic chemical form and concentration on *Spartina patens* and *Spartina alterniflora* growth and tissue arsenic concentration. *Plant Soil* 1998; **198** : 33-43.

40. Odanaka Y, Tsuchiya N, Matano O, Goto S. Absorption, translocation and metabolism of the arsenical fungicides, iron methanearsonate and ammonium iron methanearsonate, in rice plants. *J Pestic Sci* 1987; **12** : 199-208.

41. Frans R, Horton D, Burdette L. Influence of MSMA on straighthead, arsenic uptake and growth response in rice (*Oryza sativa*). *Arkabsas AES Rep Ser* 1988; **302** : 1-12.

42. Machlis L. Accumulation of arsenic in the shoots of sudan grass and bush beans. *Plant Physiol* 1941; **16** : 521-544.

43. Tsutsumi M. Intensification of arsenic toxicity to paddy rice by hydrogen sulphide and ferrous iron I. Induction of bronzing and accumulation in rice by arsenic. *Soil Sci Plant Nutr* 1980; **26** : 561-569.

44. Carbonell-Barrachina A, Burlo Carbonell F, Mataix Beneyto J. Arsenic uptake, distribution, and accumulation in tomato plants: effect of arsenic on plant growth and yield. *J Plant Nutr* 1995; **18** : 1237-1250.

45. Miteva E. Arsenic accumulation and effect on green bean plants development. *Bulg J Agric Sci* 1998; **4** : 583-590.

46. Miteva E. Accumulation and effect of arsenic on tomatoes. *Commun Soil Sci Plant Anal* 2002; **33** : 1917-1922.

47. Päivöke A. The long-term effects of lead and arsenate on the growth and development, chlorophyll content and nitrogen fixation of the garden pea. *Ann Bot Fennici* 1983; **20** : 297-306.

48. Das HK, Roy SC. Metabolism of L-glutamic acid in plant mitochondria: II. Some characteristics of L-glutamic acid oxidation. *Arch Biochem Biophys* 1962; **96** : 445-454.

49. Lieberman M, Biale JB. Cofactor Requirements for Oxidation of Alpha-Keto Acids by Sweet Potato Mitochondria. *Plant Physiol* 1956; **31** : 425-429.

50. Jha AB, Dubey RS. Arsenic exposure alters activity behaviour by key nitrogen assimilatory enzymes in growing rice. *Plant Growth Regul* 2004; **43** : 259-268.

51. Jain M, Gadre R. Effect of As on chlorophyll and protein contents and enzyme activities in greening maize tissues. *Water Air Soil Pollut* 1997; **93** : 109-115.

52. Srivastava S, Mishra S, Tripathi RD, Dwivedi S, Trivedi PK, Tandon PK. Phytochelatins and antioxidant systems respond differentially during arsenite and arsenate stress in *Hydrilla verticillata* (L.f.) Royle. *Environ Sci Technol* 2007; **41** : 2930-2936.

53. Hartley-Whitaker J, Ainsworth G, Meharg AA. Copper- and arsenate-induced oxidative stress in *Holcus lanatus* L. clones with differential sensitivity. *Plant Cell Environ* 2001; **24** : 713-722.

54. Abedin MJ, Feldmann J, Meharg AA. Uptake kinetics of arsenic species in rice plants. *Plant Physiol* 2002; **128**: 1120-1128.

55. Abedin MJ, Cresser MS, Meharg AA, Feldmann J, Cotter-Howells J. Arsenic accumulation and metabolism in rice (*Oryza sativa* L.). *Environ Sci Technol* 2002; **36** : 962-968.

56. Liu WJ, Zhu YG, Smith FA, Smith SE. Do phosphorus nutrition and iron plaque alter arsenate (As) uptake by rice seedlings in hydroponic culture? *New Phytol* 2004; **162** : 481-488.

57. Jha AB, Dubey RS. Carbohydrate metabolism in growing rice seedlings under arsenic toxicity. *J Plant Physiol* 2004; **161** : 867-872.

58. Mishra S, Dubey RS. Inhibition of ribonuclease and protease activities in arsenic exposed rice seedlings: role of proline as enzyme protectant. *J Plant Physiol* 2006; **163** : 927-936.

59. Williams PN, Price AH, Raab A, Hossain SA, Feldmann J, Meharg AA. Variation in arsenic speciation and concentration in paddy rice related to dietary exposure. *Environ Sci Technol* 2005; **39** : 5531-5540.

60. Wang S, Mulligan CN. Natural attenuation processes for remediation of arsenic contaminated soils and groundwater. *J Hazar Mat* 2006; **138** : 459-470.

61. Salt DE, Smith RD, Raskin I. Phytoremediation. *Annu Rev Plant Physiol Plant Mol Biol* 1998; **49** : 643-668.

62. Lasat MM. Phytoextraction of Toxic Metals: A Review of Biological Mechanisms. *J Environ Qual* 2002; **31** : 109-120.

63. Cunningham SD, Berti WR. Phytoextraction and phytostabilization: technical, economic, and regulatory considerations of the soil-lead issue. In: Terry N, Bañuelos G, editors. Phytoremediation of Contaminated Soils and Waters. Boca Raton : CRC Press, 2000. pp. 359-375.

64. Alkorta I, Hernandez-Allica J, Garibsu C. Plants against the global epidemic of arsenic poisoning. *Environ Intl* 2004; **30** : 949-951.

65. Krämer U. Phytoremediation: novel approaches to cleaning up polluted soils. *Curr Opin Biotechnol* 2005; **16** : 133-141.

66. LeDuc DL, Terry N. Phytoremediation of toxic trace elements in soil and water. *J Ind Microbiol Biotechnol* 2005; **32**: 514-520.

67. Meagher RB, Heaton AC. Strategies for the engineered phytoremediation of toxic element pollution: mercury and arsenic. *J Ind Microbiol Biotechnol* 2005; **32** : 502-13.

68. Baker AJM, Brooks RR. Terrestrial higher plants which hyperaccumulate metallic elements-a review of their distribution, ecology and phytochemistry. *Biorecovery* 1989; **1** : 81-126.

69. Mkandawire M, Dudel EG. Accumulation of arsenic in *Lemna gibba* L. (duckweed) in tailing waters of two abandoned uranium mining sites in Saxony, Germany. *Sci Total Environ* 2005; **336** : 81-89.

70. Robinson B, Kim N, Marchetti M, Moni C, Schroeter L, van den Dijssel C, Milne G, Clothier B. Arsenic hyperaccumulation by aquatic macrophytes in the Taupo Volcanic Zone, New Zealand. *Environ Exp Bot* 2006; **58**: 206-215.

71. Gonzaga MIS, Santos JAG, MA LQ. Arsenic phytoextraction and hyperaccumulation by fern species. *Sci Agric Piracicaba Braz* 2006; **63** : 90-101.

72. Ma LQ, Komar KM, Tu C, Zhang WH, Cai Y, Kennelley ED. A fern that hyperaccumulates arsenic - A hardy, versatile, fast-growing plant helps to remove arsenic from contaminated soils. *Nature* 2001; **409** : p. 579.

73. Zhao FJ, Dunham SJ, McGrath SP. Arsenic hyperaccumulation by different fern species. *New Phytol* 2002; **15** : 27-31.

74. Elless MP, Poynton CY, Willms CA, Doyle MP, Lopez AC, Sokkary DA, Ferguson BW, Blaylock MJ. Pilot-scale demonstration of phytofiltration for treatment of arsenic in New Mexico drinking water. *Water Res* 2005; 39 : 3863-3872.

75. Madeira PT, Jacono CC, Van TK. Monitoring *Hydrilla* using two RAPD procedures and the nonindigenous aquatic species database. *Aquat Plant Manage* 2000; **38**: 33-40.

76. Lee CK, Low KS, Hew NS. Accumulation of arsenic by aquatic plants. *Sci Total Environ* 1991; **103** : 215-227.

77. Dwivedi S, Srivastava S, Mishra S, Dixit B, Kumar A, Tripathi RD. Screening of native plants and algae growing on fly-ash affected areas near National Thermal Power Corporation, Tanda, Uttar Pradesh, India for accumulation of toxic heavy metals *J. Hazard Mater* 2008; **158(2-3)** : 359-365.

78. Dushenkov WT, Bright DA, Reimer KJ. Arsenic bioaccumulation and toxicity in aquatic macrophytes exposed to gold-mine effluent: relationships with environmental partitioning, metal uptake and nutrients. *Aqua Bot* 1995; **50** : 141-158.

79. Lancaster RJ, Coup MR, Hughes JW. Toxicity of arsenic present in lakeweed. *New Zealand Vet J* 1971; **19** : 141-145.

80. Aggett J, Aspell AC. Arsenic from geothermal sources. New Zealand Research and Development Committee Report 35. University of Auckland, Auckland, New Zealand, 1978.

81. Reeves RD, Liddle JR. Dispersal of arsenic from geothermal sources of the central North Island. In: Baker MJ, editor. Trace Elements in the Eighties, Palmerston North: NZ Trace Element Group, 1986.

82. Robinson BH, Brooks RR, Outred HA, Kirkman JH. The distribution and fate of arsenic in the Waikato river system, North Island, New Zealand. *Chem Spec Bioavailab* 1995; **7** : 89-96.

83. Robinson BH, Duwig C, Bolan NS, Kannathasan M, Saravanan A. Uptake of arsenic by NewZealand water-cress (*Lepidium sativum*). *Sci Total Environ* 2003; **301**: 67-73.

84. Mishra S, Srivastava S, Tripathi RD, Trivedi PK. Thiol metabolism and antioxidant systems complement each other during arsenate detoxification in *Ceratophyllum demersum* L. *Aqua Toxicol* 2008; **86** : 205-215.

85. Mkandawire M, Lyubun YV, Kosterin PV, Dudel EG. Toxicity of arsenic species to *Lemna gibba* L. and the influence of phosphate on arsenic bioavailability. *Environ Toxicol* 2004; **19** : 26-34.

86. Hoffmann T, Kutter C, Santamaria JM. Capacity of *Salvinia minima* Baker, to tolerate and accumulate As and Pb. *Eng Life Sci* 2004; **4** : 61-65.

87. Almela C, Laparra JM, Ve´lez D, Montoro R, Barbera´ R, Farre´ R. Arsenosugars in raw and cooked edible seaweeds: characterization and bioaccessibility. *J Agric Food Chem* 2005; **53** : 7344-7351.

88. Nischwitz V, Pergantis SA. First report on the detection and quantification of arsenobetaine in extracts of marine algae using HPLC-ES-MS/MS. *Analyst* 2005; **130** : 1348-1350.

89. Morita M, Shibata Y. Chemical form of arsenic in marine macroalgae-review. *Appl Organomet Chem* 1990; **4** : 181-190.

90. Francesconi KA, Edmonds JS. Arsenic and marine organisms. *Adv Inorg Chem* 1997; **44** : 147-189.

91. Asher CJ, Reay PF. Arsenic uptake by barley seedlings. *Aust J Plant Physiol* 1979; **6** : 459-466.

92. Meharg AA, Macnair MR. Suppression of the high affinity phosphate uptake system: a mechanism of arsenate tolerance in *Holcus lanatus*. *J Exp Bot* 1992; **43** : 519-524.

93. Rosen BP. Biochemistry of arsenic detoxification. *FEBS Lett* 2002; **529** : 86-92.

94. Meharg AA, Jardine L. Arsenite transport into paddy rice (*Oryza sativa*) roots. *New Phytol* 2003; **157** : 39-44.

95. Meharg AA. Arsenic in rice- understanding a new disaster for South-East Asia. *Trends Plant Sci* 2004; **9** : 415-417.

96. Lombi E, Zhao FJ, Fuhrmann M, Ma LQ, McGrath SP. Arsenic distribution and speciation in the fronds of the hyperaccumulator *Pteris vittata*. *New Phytol* 2002; **156**: 195-203.

97. Wang J, Zhao FJ, Meharg AA, Raab A, Feldmann J, McGrath SP. Mechanisms of arsenic hyper accumulation in *Pteris vittata*. Uptake kinetics, interactions with phosphate, and arsenic speciation. *Plant Physiol* 2002; **130** : 1552-1561.

98. Ze-Chun H, Tong-Bin C, Lei M, Tian-Dou H. Direct determination of arsenic species in arsenic hyperaccumulator *Pteris vittata* by EXAFS. *Acta Bot Sin* 2004; **46** : 46-50.

99. Hokura A, Omuma R, Terada Y, Kitajima N, Abe T, Saito H, Yoshida S, Nakai I. Arsenic distribution and speciation in an arsenic hyperaccumulator fern by X-ray spectroscopy utilizing a synchrotron radiation source. *J Anal At Spectrom* 2006; **21** : 321-328.

100. Pickering IJ, Gumaelius L, Harris HH, Prince RC, Hirsch G, Banks JA, Salt DE, George GN. Localizing the bio-chemical transformations of arsenate in a hyper accumulating fern. *Environ Sci Technol* 2006; **40** : 5010-5014.

101. Wu JH, Zhang R, Lilley RM. Methylation of arsenic in vitro by cell extracts from bentgrass (*Agrostis tenuis*): effect of acute exposure of plants to arsenate. *Func Plant Biol* 2002; **29** : 73-80.

102. Zhao R, Zhao M, Wang H, Taneike Y, Zhang X. Arsenic speciation in moso bomboo shoot - A terrestrial plant that contains organoarsenic species. *Sci Total Environ* 2006; **371** : 293-303.

103. Zhang WH, Cai Y, Tu C, Ma LQ. Arsenic speciation and distribution in an arsenic hyper accumulating plant. *Sci Total Environ* 2002; **300** : 167-177.

104. Zhao FJ, Wang JR, Barker JHA, Schat H, Bleeker PM, McGrath SP. The role of phytochelatins in arsenic tolerance in the hyper accumulator *Pteris vittata*. *New Phytol* 2003; **159** : 403-410.

105. Francesconi K, Visoottiviseth P, Sridokchan W, Goessler W. Arsenic species in an arsenic hyper accumulating fern, *Pityrogramma calomelanos*: a potential phytoremediator of arsenic-contaminated soils. *Sci Total Environ* 2002; **284**: 27-35.

106. Shibata Y, Morita M. Characterization of organic arsenic compounds in bivalves. *Appl Organomet Chem* 1992; **6**: 343-349.

107. Edmonds JS, Francesconi KA. Arseno-sugars from brown kelp (*Ecklonia radiata*) as intermediates in cycling of arsenic in a marine ecosystem. *Nature* 1981; **289** : 602-604.

108. Shibata Y, Morita M, Edmonds JS. Purification and identification of arsenic-containing ribofuranosides from the edible brown seaweed, *Laminaria japonica* Makonbu *Agric Biol Chem* 1987; **51** : 391-398.

109. Francesconi KA, Edmonds JS, Stick RV, Skelton BW, White AH. Arsenic-containing ribosides from the brown alga *Sargassum lacerifolium*-X-ray molecular-structure of 2-amino-3-[50-deoxy-50-(dimethylarsinoyl)-ribosyloxy] propane-l-sulfonic acid. *J Chem Soc Perkin Trans* 1991; **1** : 707-2716.

110. Francesconi KA, Edmonds JS. Arsenic species in marine samples. *Croat Chem Acta* 1998; **71** : 343-359.

111. Larsen EH, Pritzl G, Hansen SH. Arsenic speciation in seafood samples with emphasis on minor constituents: an investigation by high performance liquid chromatography with detection by inductively coupled plasma mass spectrometry *J Anal Spectrom* 1993; **8** : 1075-1084.

112. Maeda S, Kusadome K, Arima H, Ohki A, Naka K. Biomethylation of arsenic and its excretion by the alga *Chlorella vulgaris. Appl Organometal Chem* 1992; **6** : 407-413.

113. Zheng J, Hintelmann H, Dimock B, Dzurko MS. Speciation of arsenic in water, sediment, and plants of the Moira watershed, Canada, using HPLC coupled to high resolution ICP-MS. *Anal Bioanal Chem* 2003; **377** : 14-24.

114. Bowen HJM. Environmental chemistry of the elements. London: Academic Press, 1979.

115. Kuehnelt D, Lintschinger J, Goessler W. Arsenic compounds in terristrial organisms. iv Green plants and lichens from an old arsenic smeller site in Austria *Appl Organomet Chem* 2000; **14(8)** : p. 411-420.

116. Koch I, Wang L, Ollson CA, Cullen WR, Reimer KJ. The predominance of inorganic arsenic species in plants from Yellowknife, Northwest Territories, Canada. *Environ Sci Technol* 2000; **34** : 22-26.

117. Onken BM, Hossner LR. Plant uptake and determination of arsenic species in soil solution under flooded conditions. *J Environ Qual* 1995; **24** : 373-381.

118. Schoof RA, Yost LJ, Eickhoff J, Crecelius EA, Cragin DW, Meacher DM, Menzel DB. A market basket survey of inorganic arsenic in food. *Food Chem Toxicol* 1999; **37** : 839-846.

119. Heitkemper DT, Vela NP, Stewart KR, Westphal CS. Determination of total and speciated arsenic in rice by ion chromatography and inductively coupled plasma mass spectrometry. *J Anal Atomic Spect* 2001; **16** : 299-306.

120. Meharg AA, Rahman M. Arsenic contamination of Bangladesh paddy field soils: implications for rice contribution to arsenic consumption. *Environ Sci Technol* 2003; **37** : 229-234.

121. Islam MR, Jahiruddin M, Islam S. Assessment of arsenic in the water-soil-plant systems in Gangetic flood plains of Bangladesh. *Asian J Plant Sci* 2004; **3** : 489-493.

122. Juhasz AL, Smith E, Weber J, Rees M, Rofe A, Kuchel T, Sansom L, Naidu R. *In vivo* assessment of arsenic bioavailability in rice and its significance for human health risk assessment. *Environ Health Perspec* 2006; **114** : 1826-1831.

123. Armstrong W. Oxygen diffusion from the roots of some British bog plants. *Nature* 1964; **204** : 801-802.

124. Armstrong W. The oxidising activity of roots in waterlogged soils. *Physiol Plant* 1967; **20** : 920-926.

125. Chen CC, Dixon JB, Turner FT. Iron coatings on rice roots: morphology and models of development. *Soil Sci Soc Am J* 1980; **44** : 1113-1119.

126. Taylor GJ, Crowder AA. Use of DCB technique for extraction of hydrous iron oxides from roots of wetland plants. *Am J Bot* 1983; **70** : 1254-1257.

127. Taylor GJ, Crowder AA, Rodden R. Formation and morphology of an iron plaque on the roots of *Typha latifolia* L. grown in solution culture. *Am J Bot* 1984; **71** : 666-675.

128. Hansel CM, La Force MJ, Fendorf S, Sutton S. Spatial and temporal association of As and Fe species on aquatic plant roots. *Environ Sci Technol* 2002; **36** : 1988-1994.

129. Bacha RE, Hossner LR. Characteristics of coating formed on rice roots as affected by Fe and Mn additions. *Soil Sci Soc Am J* 1977; **41** : 931-935.

130. Hansel CM, Fendorf S, Sutton S, Newville M. Characterization of Fe plaque and associated metals on the roots of mine-waste impacted aquatic plants. *Environ Sci Technol* 2001; **35** : 3863-3868.

131. Belzile N, Tessier A. Interactions between arsenic and iron oxyhydroxides in lacustrine sediments. *Geochimca et Cosmochimca Acta* 1990; **54** : 103-109.

132. Meng XG, Korfiatis GP, Bang S, Bang KW. Combined effects of anions on arsenic removal by iron hydroxides. *Toxicol Lett* 2002; **133** : 103-111.

133. Otte ML, Dekkers MJ, Rozema J, Broekman RA. Uptake of arsenic by *Aster tripolium* in relation to rhizosphere oxidation. *Can J Bot* 1991; **69** : 2670-2677.

134. Liu WJ, Zhu YG, Smith FA, Smith SE. Do iron plaque and genotypes affect arsenate uptake and translocation by rice seedlings (*Oryza sativa* L.) grown in solution culture? *J Exp Bot* 2004; **55** : 1707-1713.

135. Chen Z, Zhu YG, Liu WJ, Meharg AA. Direct evidence showing the effect of root surface iron plaque on arsenite and arsenate uptake into rice (*Oryza sativa*) roots. *New Phytol* 2005; **165** : 91-97.

136. Bleeker PM, Hakvoort HWJ, Bliek M, Souer E, Schat H. Enhanced arsenate reduction by a CDC25-like tyrosine phosphatase explains increased phytochelatin accumulation in arsenate-tolerant *Holcus lanatus*. *Plant J* 2006; **45**: 917-929.

137. Mittler R. Oxidative stress, antioxidants and stress tolerance. *Trends Plant Sci* 2002; **7** : 405-410.

138. Dhankher OP, Rosen BP, McKinney EC, Meagher RB. Hyper accumulation of arsenic in the shoots of *Arabidopsis* silenced for arsenate reductase (ACR2). *Proc Natl Acad Sci USA* 2006; **103** : 5413-5418.

139. Ellis DR, Gumaelius L, Indriolo E, Pickering IJ, Banks JA, Salt DE. A novel arsenate reductase from the arsenic hyper accumulating fern *Pteris vittata*. *Plant Physiol* 2006; **141** : 1544-1554.

140. Duan GL, Zhou Y, Tong YP, Mukhopadhyay R, Rosen BP, Zhu YG. A CDC25 homologue from rice functions as an arsenate reductase. *New Phytol* 2007; **174** : 311-321.

141. Schat H, Llugany M, Vooijs R, Hartley-Whitaker J, Bleeker PM. The role of phytochelatins in constitutive and adaptive heavy metal tolerances in hyper accumulator and non-hyper accumulator metallophytes. *J Exp Bot* 2002; **53** : 2381-2392.

142. Hartley-Whitaker J, Ainsworth G, Vooijs R, Ten Bookum WM, Schat H, Meharg AA. Phytochelatins are involved in differential arsenate tolerance in *Holcus lanatus* L. *Plant Physiol* 2001; **126** : 299-306.

143. Bleeker PM, Schat H, Vooijs R, Verkleij JAC, Ernst WHO. Mechanisms of arsenate tolerance in *Cytisus striatus*. *New Phytol* 2003; **157** : 33-38.

144. Cai Y, Su J, Ma LQ. Low molecular weight thiols in arsenic hyper accumulator *Pteris vittata* upon exposure to arsenic and other trace elements. *Environ Pollut* 2004; **129** : 69-78.

145. Cao X, Ma LQ, Tu, C. Antioxidative responses to arsenic in the arsenic-hyper accumulator Chinese brake fern (*Pteris vittata* L.). *Environ Pollut* 2004; **128** : 317-325.

146. Pickering IJ, Prince RC, George MJ, Smith RD, George GN, Salt DE. Reduction and coordination of arsenic in Indian Mustard. *Plant Physiol* 2000; **122** : 1171-1177.

147. Schmöger MEV, Oven M, Grill E. Detoxification of arsenic by phytochelatins in plants. *Plant Physiol* 2000; **122** : 793-801.

148. Montes-Bayón M, Meija J, LeDuc DL, Terry N, Caruso JA, Sanz-Medel A. HPLC-ICP-MS and ESI-Q-TOF analysis of biomolecules induced in *Brassica juncea* during arsenic accumulation. *J Anal At Spectrom* 2004; **19** : 153-158.

149. Raab A, Feldmann J, Meharg AA. The nature of arsenic-phytochelatin complexes in *Holcus lanatus* and *Pteris cretica*. *Plant Physiol* 2004; **134** : 1113-1122.

150. Raab A, Schat H, Meharg AA, Feldmann J. Uptake, translocation and transformation of arsenate and arsenite in sunflower (*Helianthus annuus*): formation of arsenic-phytochelatin complexes during to high arsenic concentrations. *New Phytol* 2005; **168** : 551-558.

151. Elstner EF. Mechanisms of oxygen activation in different compartments of plant cells. In: Pell EJ, Steffen KL, editors. Active oxygen/oxidative stress and plant metabolism, Rockville, MD: American Society of Plant Physiologists, 1991. pp. 13-25.

152. Elstner EF, Wagner GA, Schütz W. Activated oxygen in green plants in relation to stress situation. *Curr Top Plant Biochem Physiol* 1988; **7** : 159-187.

153. Mylona PV, Polidoros AN, Scandalios JG. Modulation of antioxidant responses by arsenic in maize. *Free Rad Biol Med* 1998; **25** : 576-585.

154. Li Y, Dhankher OP, Carreira L, Lee D, Chen A, Schroeder JI, Balish RS, Meagher RB. Overexpression of phytochelatin synthase in *Arabidopsis* leads to enhanced arsenic tolerance and cadmium hypersensitivity. *Plant Cell Physiol* 2004; **45** : 1787-1797.

155. Picault N, Cazale AC, Beyly A, Cuine S, Carrier P, Luu DT, Forestier C, Peltier G. Chloroplast targeting of phytochelatin synthase in *Arabidopsis*: effects on heavy metal tolerance and accumulation. *Biochimie* 2006; **88** : 1743-1750.

156. Duan GL, Zhu YG, Tong YP, Cai C, Kneer R. Characterization of arsenate reductase in the extract of roots and fronds of Chinese brake fern, an arsenic hyper accumulator. *Plant Physiol* 2005; **138** : 461-469.

157. Ghosh M, Shen J, Rosen BP. Pathway of As(III) detoxification in *Sachharomyces cerevisiae*. *Proc Natl Acad Sci* USA 1999; **96** : 5001-5006.

158. NBRI (National Botanical Resaerch Institute, Lucknow) Annual Report, 2006-2007.

Proceedings of the National Academy of Sciences, India

Section B: Biological Sciences

Instructions to Authors

A. What to submit

The journal publishes reviews or papers in any area of biological sciences. Special issue of the journal on proceedings of National and International Conferences/ Symposia can also be published with one or more of the organizers as Guest Editors. At least one of the Guest Editors should be Fellow of the Academy. Guest Editors shall be responsible for ensuring quality and proper referring of the papers.

1. Review Article: It should be a critical review highlighting present status and an overview of the past work on a topic of current interest. It should help either in initiating research activity in that particular area or in increasing the comprehension of the current challenges. The contributors should preferably submit a brief pre-concept note or a two-page summary to the Chief Editor before preparing the review. If the review is accepted for publication, Rupees two thousand would be given to the 'corresponding author' after its publication to cover expenses towards its preparation. A review article should not exceed 30 printed pages (word limit 10,000).

2. Original Article: It should give results of the original research work done by the authors. Ordinarily, such articles should not exceed 12 printed pages (word limit 3,600).

B. Who can submit?

1. Investigators (Indian or Foreign) are welcome to submit manuscript for publication.

2. Fellows of the National Academy of Sciences, India can forward quality papers in their research field for publication in the journal. The name of the communicating Fellow would be printed in the paper as " Communicated by ....FNASc"

The communicating Fellow should certify that:

a). The forwarded paper is in his/her field of specialization.

b). He/she has read the paper and reviewed it carefully. The Editorial Board, however, may get the paper reviewed by another referee if necessary.

C. Whom to submit

Original plus two hard copies of the manuscript should be sent to the Managing Editor (Biological Sciences), Proceedings of the National Academy of Sciences, India, 5 Lajpat Rai Road, New Katra, Allahabad-211 002, India. Electronic version (CD or 3.5" floppy disk) of the final copy would be required when the paper is accepted for publication.

D. How to submit

Authors may submit the manuscript directly or through a Fellow of the Academy as described above.

E. Format of the manuscript

1.The Proceedings is published in two column format on A4 page.

2.The manuscript should be typed double spaced in 12-font size (Arial/Times/Times New Roman) on one side of good quality A4 size paper with one inch margins. Insert hard returns only at the end of the paragraphs. Page number should appear in the upper right hand corner of each page, beginning with the title page. File format for the text are MSWord, WordPerfect or LaTeX. Figures may be submitted as TIFF, EPS, PS, GIF, JPEG, or PPT files.

Title Page

a). **Title** of the papers should be in **bold** (14 font size) and centered near the top of the first page.

b). **Author's names** should be in **bold** while **affiliations** should be in italics. Authors who are the Fellows of the Academy should write FNASc after their names.

Arrangement of the text

a). The text of the paper should be arranged into Abstract, Introduction, Materials and Methods, Results, Discussion, Conclusions, Acknowledgements and References.

b). **Abstract** (about 150 words) should be both in English and Hindi; and typed in **bold**.

c). **Keywords** [maximum 5, each separated by comma (,)] and a **short running title** (maximum 50 characters including spaces) should follow the **Abstract**.

d). All **figures** should be numbered consecutively using Arabic numerals. Line drawings and inscriptions should be legible. In case of scanned figures/line drawings, minimum resolution of 800 dpi should be used. All figures should be labeled on the back to indicate figure numbers, top margin and authors. Legends should be brief, self explanatory, typed on separate page and placed at the end of the text.

e). **Tables** should be numbered consecutively using Arabic numerals, have self-explanatory title and submitted separately from the text. Footnotes to tables should be indicated by superscript lower-case letters. Abbreviations should be explained in the footnotes.

f). **References** should be indicated in the text by superscript Arabic numerals. The list of references should be arranged in order of their occurrence in the text References should be given in the following style:

Journal article:
Khosla P, Bhargawa S, Singh J, Srivastava RK. Antinociceptive activity of *A. indica* (Neem) in rats. *Indian J Pharmacol* 2000;**32**:372-374.

Book:
Dhawan BN, Srimal RC. Laboratory Manual for Pharmacological Evaluation of Natural Products. First Edition, Trieste: International Center for Science and High Technology, 1997.

Book Chapter/Paper in Conference Proceedings:
Sriramana K, Nagaraju J. Conservation of biodiversity in genomic era. In: Tandon P, Sharma M, Swaroop R, editors. Biodiversity Status and Propectus. New Delhi: Narosa Publishing House, 2005. pp.150-168.

Abstract in Conference/ Symposium:
Singh MM, Gupta CM. Contraceptives from Natural Sources: Experiences and prospects. Proceedings of the Symposium on Expanding Contraceptive Choices: International and Indian Experiences and their Implications for Policies and Programmes, 2003, 7-8 December, Mumbai, India.

Dissertation:
Mehra PS. A clinical study on the effect of Amrita-Pippali-Nimba Yoga in cases of NIDDM with special reference to the role of Agni and Ogas. MD (Ay). Thesis, Banaras Hindu University, Varanasi,1999.

Patent:
Srivastava N, Singh MM, Ray S. A process for the preparation of tertiary aminoalkoxy derivatives of substituted diaryl-5,6,7,8-tetrahydronaphthyl methane and their salts useful as fertility regulating agents. Indian Patent 187178, Central Drug Research Institute, Lucknow, 1998.

Website:
URI of the Wewbsite should be mentioned e.g., www.nasi.org.in

Abbreviations of the names of journal/periodicals should conform to those given in the World list of Scientific Periodicals.

F. Preparation of Electronic version (CD or 3.5" floppy disk)

Ensure that your manuscript files are virus-free. Use only a new CD or floppy disk. Write the following information on the disk label:

1. File name(s)

2. Name of software and version used
3. Name of corresponding author
4. Dispatch date

G. Miscellaneous

1. All papers will be reviewed by the Editorial Board or External referees.

2. If a revision is recommended, three copies of the revised manuscript must be returned within two months of receipt of referees comments, otherwise it would be processed as a fresh manuscript. The covering letter should indicate the changes made in response to referees comments.

3. Upon acceptance of the paper, authors will be asked to transfer copyright of the paper to the publisher. This transfer will ensure wide dissemination of information.

4. Corresponding author will receive galley proof of the paper from the Academy's Editorial Office. Only typesetting errors can be corrected. No change and/or addition to the accepted manuscript will be allowed. In exceptional cases, a short post-script may be permitted. The corrected proof must be returned within a week of its receipt, otherwise the paper will be published with the corrections done by the Editorial Office.

5. Manuscripts not accepted for publication will not be returned unless specifically requested by the corresponding author.

6. Twenty-five offprints will be provided free of cost to the corresponding author. Purchase of additional offprints should be ordered on the form accompanying the proof.

SUBSCRIPTION RATE OF THE JOURNALS

Annual Subscription for both Sections (Sec A – Physical Sciences and Sec B – Biological Sciences) : Rs 500 00, **for each Section** Rs. 250.00; **Single Copy :** Rs. 100.00, **Foreign Subscription :** (a) for one Section US $100, (b) for both Sections US $200. **(Air Mail charges included in foreign subscription)**

The National Academy of Sciences, India

(Registered under Act XXI of 1860)
Founded 1930

CONTENTS